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FLYING TRAINING MANUAL.

PART I.
FLYING INSTRUCTION.

AIR MINISTRY.

LONDON:
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FLYING TRAINING MANUAL.

PART I.

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1926

Price 2s. 6d. Net.

This manual is issued by command of the Air Council and deals with the training of pilots in the care and handling of aeroplanes and aeroplane engines.

The principles of flying training, which have been evolved by experience as generally applicable to the training of pilots, are to be strictly observed.

The authority for the definition of aeronautical terms is the British Standard Glossary of aeronautical terms prepared with the approval of the Air Council.

The definitions given at the commencement of this publication explain the meaning of terms used in the text.

By Command of the Air Council.

W F Nicholson

AIR MINISTRY,
KINGSWAY, W.C. 2.

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DEFINITIONS.

Adiabatic -	The word which is applied in the science of thermodynamics to the changes which may take place in the pressure and density of a substance when no heat is communicated to it or withdrawn from it,
Aerobatics -	Evolutions voluntarily performed with an aircraft other than those required for normal flying. (Colloquialism :—" Stunt.")
Aerofoil - -	A structure, analogous to the wing or tail of a bird, designed to obtain reaction from the air approximately at right angles to the direction of its motion. *See* fig.
Aeroplane -	Any mechanically-driven heavier-than-air aircraft with fixed wings.
Aileron - -	Aerofoils used for causing an aeroplane to roll about her longitudinal axis for the purpose of balancing. These aerofoils are usually hinged near the wing tips in continuation of the wing surfaces. They are rotated in the opposite directions by interconnected control wires attached to the control column. (*See* fig. 1.).

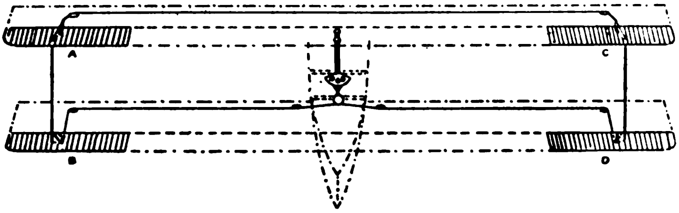
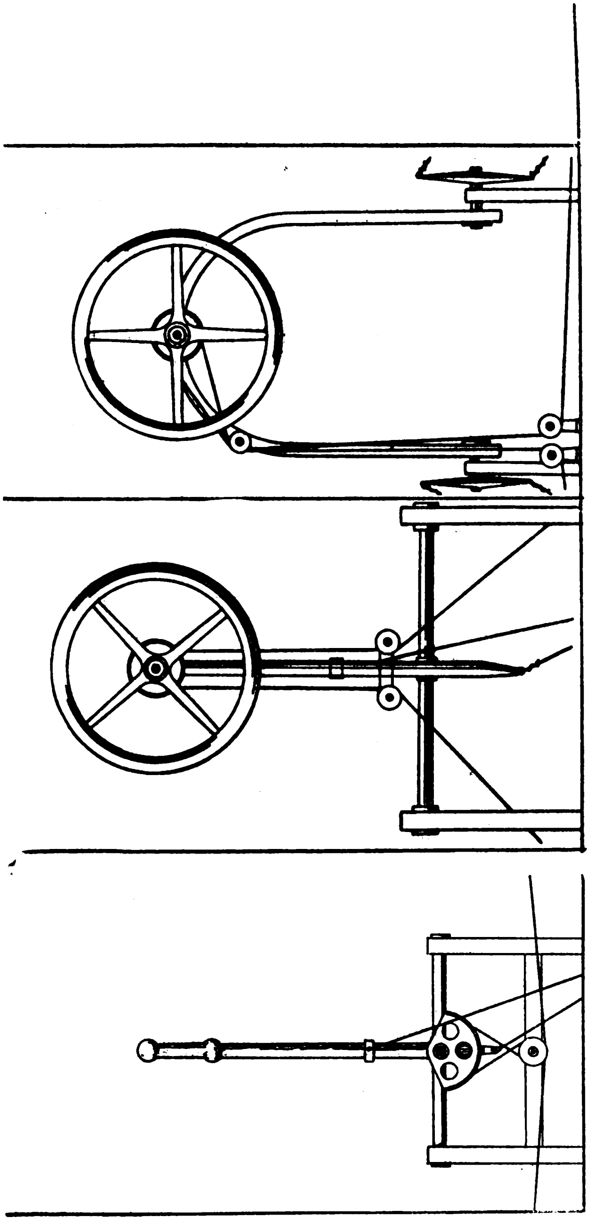


FIG. 1.—Ailerons Control.

Airmanship -	Proficiency in the knowledge of handling and operating aircraft on the ground and in the air.
Air intake pipe -	A pipe fitted to the carburettor or induction system through which only air is drawn.
Aircraft - -	A generic term for all types of air-supported vehicles.
Airscrew - -	A generic term which includes all types of screw with helical blades designed to rotate in the air. An airscrew may be either (i) tractor or (ii) propeller.
Altimeter - -	An aneroid barometer graduated to indicate height instead of pressure under specified conditions.
Altitude control	A device fitted to a carburettor or other part of the induction system in order to obtain a correct mixture of the fuel gas at varying altitudes.
Aneroid barometer.	An instrument for determining the pressure of the atmosphere, depending for its operation on the volume of a metal box exhausted of air.
Aspect ratio -	The ratio of span to cord of an aerofoil.

Axes of an aeroplane.	*See* para. 21.
Bank - -	The angle between the lateral axis of an aeroplane and the horizontal is called the angle of bank, and is denoted by symbol ϕ.
Boss of airscrew	The central portion of the airscrew by which it is attached to the airscrew hub.
Break horse-power.	The effective power available after deducting from the indicated horse-power the power absorbed by the engine friction.
"Bump" -	A colloquial term for a sharp disturbance of steady flight by a local eddy in the air.
Camber - -	The convexity of an aerofoil section. The camber is usually measured (as a fraction of the cord) by the maximum height above the cord.
Cant, to - -	To tilt, to take any inclined position.
Ceiling, absolute	The limit of height attainable in standard atmosphere under specified conditions.
Ceiling, service	The height at which the rate of climb has fallen to a certain defined limit (*e.g.*, 100 feet a minute).
Centre of gravity	That point in a body through which the resultant of the weights of its parts passes, in every position that the body can assume.
Centre of pressure.	*See* para. 18.
Centrifugal force	*See* para. 65.
Chock - -	A piece of wood or other material employed in a structure to strengthen it and to prevent movement where two or more members meet at an angle. The term is also used to denote blocks of wood or other material placed in front of the aeroplane to prevent its moving when the engine is started.
Chord - -	A straight line (taken conventionally fore and aft, unless otherwise specified) touching the under surface of an aerofoil at or near the leading and trailing edges. The length of the chord is the projected length of a section of a plane, *i.e.*, normally the length of a line joining the leading and trailing edges. In an aerofoil having compound curvature the chord requires special definition.
Clinometer or Abney Level.	A type of spirit-level protractor, used for measuring angles (angle of incidence).
Cockpit - -	The portion of a fuselage or nacelle designed to accommodate pilot and crew. (*See* fig. 87.)
"Contact" -	The word used to denote that the switch is "On." Actually, "making contact" removes a short circuit from the ignition system.
Control column	The lever (or the pillar supporting a hand-wheel) by which the elevator and aileron controls are operated. (Colloquialism :—"Stick."—*See* fig. 2.)
Control cables -	Cables or wires connecting the rudder bar and the control column to their respective surfaces. (*See* figs. 1, 2, 3).
Cowling - -	The metal covering for an engine.



(a) Lever control column.

(b) Wheel and lever control column.

(c) Wheel and U control column.

FIG. 2.

Dihedral angle - In geometry—the angle between two planes. The planes of an aeroplane are at a dihedral angle

	when both port and starboard are inclined upwards or downwards to the transverse axis. If the inclination is upward the dihedral is positive; if downward the dihedral is negative.
Dope	A chemical preparation employed to tighten the fabric and, by filling up interstices of the fabric, to give a continuous surface and prevent penetration by air or moisture.
Drag	The resistance along the line of flight; the head resistance, *i.e.*, the total resistance of the whole aircraft, including wings, undercarriage, etc.
Drift, to	To move sideways or crab-wise over the ground. It is caused by a cross-wind which moves both aeroplane and the surrounding medium with relation to the earth. Drifting should not be confused with skidding or side-slipping which are sideway movements with relation to the air. Drift is measured by the change in direction of the course in degrees port or starboard, as the angle between the course steered and the track made good.
Duct	A channel or groove for oil.
Elevator	The horizontal control surface by which the upward or downward inclination of an aeroplane in flight is controlled. The elevator is usually hinged to the trailing edge of the tail plane. (*See* fig. 3).

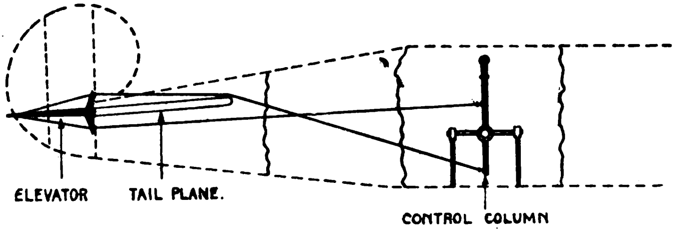


FIG. 3.—Elevator Control.

Empennage	Tail unit.
Exhaust pipe	A pipe through which exhaust gas is expelled from the cylinder.
Fabric	An outer covering of the main plane structure, control surfaces and fuselage. It is generally made of linen, which is painted with a chemical preparation ("dope") to cause it to tauten, and to preserve it from the effects of the weather.
Fairing	A piece added to any structure to reduce its head resistance or drag.
Fin-surface	The sum of all those areas on the aircraft which give rise to side pressure when the aircraft slips. Normally it amounts to the projected area of the components of the aircraft shown in side elevation, including the airscrew and the projected area of the main plane due to dihedral.
Fins	Vertical surface or surfaces forming part of the tail unit by which the yawing of an aeroplane in flight is controlled.
Flattening out	The change of the path of flight from the gliding angle to a path parallel to the ground.

Flying position	The position of an aeroplane in which its longitudinal axis is parallel to the ground.
Fuselage	The main structure or body of most types of aeroplanes, to which the main planes, tail unit and other surfaces are attached. (*See* also "Nacelle"). (*See* figs. 84, 85).
Ground speed	The relative speed of an aeroplane in flight over the ground when a wind is blowing.
Gyroscopic action	*See* para. 61.
Gap	The distance between one plane and the next immediately above or below it.
Horse-power	The exertion of 33,000 units of work or ft.-lbs. in the period of one minute.
Incidence rigging.	The angle between the chord of the main plane and the horizontal when the aeroplane is in the rigging position.
Induction pipe	A pipe for supplying fuel gas to one cylinder only or connecting the carburettor to the induction manifold.
Indicated horse-power.	The power actually developed in the cylinder of equal temperature.
Knot	A nautical mile.
Leading edge	The forward edge of a streamline body or aerofoil.
Leeward	Away from the wind.
Leeway	The same as "drift."
Lift	The pressure at right angles to a surface exerted by air flowing past that surface, *e.g.*, a force, perpendicular to the path of a flight of an aircraft, which sustains the aircraft in the air.
Load factor	*See* para. 71.
Longerons	The main longitudinal members of a fuselage or nacelle. (*See* figs. 84, 85.)
Loop, to	To execute a complete revolution about a lateral axis. (*See* figs. 77, 78.)
Nacelle	The term applied to bodies enclosing crew and/or engines when mounted on or between the planes of an aircraft. The difference between a nacelle and a fuselage is that the former is short and does not extend back to the tail.
"Nose dive"	A steep descent nose foremost.
"Nose heavy"	A state in which an aircraft has a tendency to lower her nose in flight.
"Pancaking"	An aeroplane is said to "pancake" when it is stalled on landing at too great a height from the ground, thus causing it to drop the remaining distance along a nearly vertical path.
Pitch (airscrew)	The distance through which an airscrew must advance along its own axis during one revolution in order to give no thrust.
Pitching	Angular motion about the lateral axis. A loop is complete revolution about that axis.
Pitot tube	A tube, of which an open end faces a current of air used as part of an apparatus for determining the speed of the current.
Plane of symmetry.	A plane dividing an object into two parts each of which is a mirror image of the other. Every aeroplane trimmed on the ground has a vertical plane cutting it fore and aft, which is approximately a plane of symmetry. In practice this plane is always referred to as the plane of symmetry. (*See* fig. 3.)

Port - - - The left-hand side as seen by the pilot looking forward. (*See* fig. 4.)

Power - - - The time rate of expending energy in doing work.

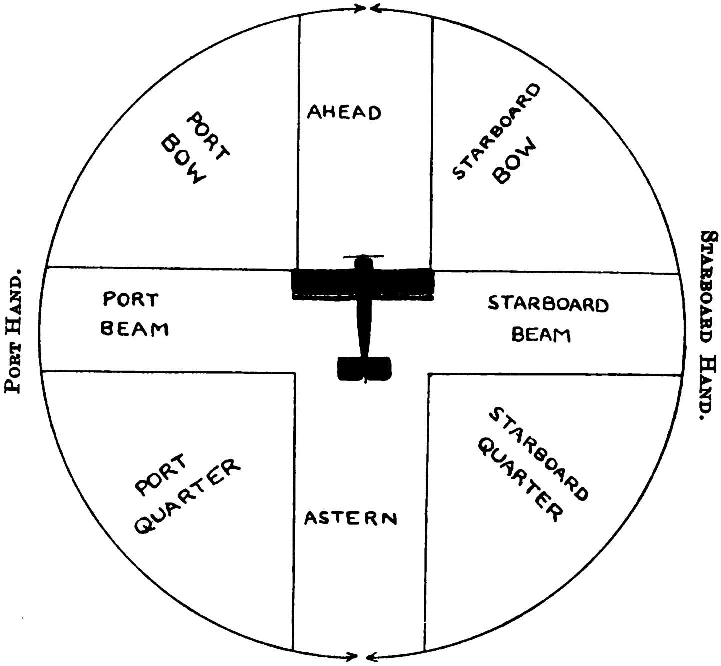


FIG. 4.—Method of indicating the position of external objects.

Rolling - - - Angular motion about the longitudinal axis. A complete revolution about that axis is commonly called a roll.

Rudder - - - The vertical surface or surfaces forming part of the tail unit, by which the yawing of the aeroplane in flight is controlled. (*See* fig. 5.)

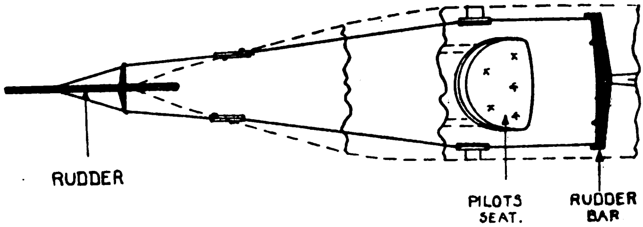


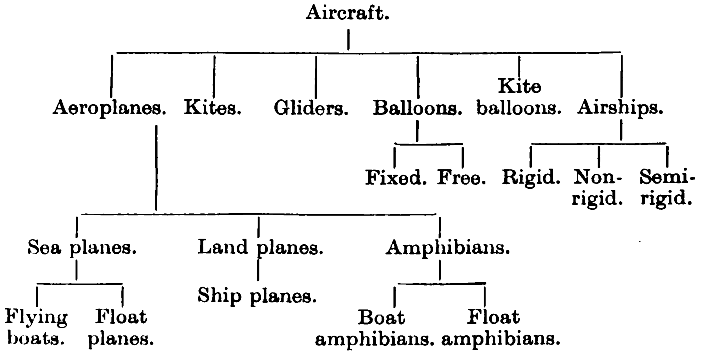
FIG. 5.—Rudder Control.

Shock absorber (cord). An elastic buffer system introduced between the skids, or wheels, and the body of an aeroplane and designed to absorb as far as possible the shock energy of alighting. Braided elastic cord is the material mostly used, on account of the very high quality of energy it can absorb for each unit of weight. (*See* fig. 50.)

Side-slipping and skidding.	Movement sideways through the air from the course ahead. Side slipping will occur, for example, when an aircraft is turned with too much bank and slips inwards and downwards. Skidding will occur when the aircraft is turned with too little bank and moves outwards.
Side-looping	A loop that lies at an angle to the vertical.
Skin friction	The resistance caused by the movement of a fluid (*e.g.*, air) over the surface of a body.
Slipstream	The stream of air that is discharged aft by a revolving airscrew.
Span	The overall distance from wing tip to wing tip.
Spar	A principal member of the main planes or control surfaces that support subordinate members.
Spinning dive	A diving descent combined with a continued rotation about the direction of motion of the centre of gravity of an aeroplane.
Spiral glide	A banked continuous gliding turn, with the engine giving no thrust.
Stability	The quality by virtue of which any disturbance of steady motion tends to decrease. A given type of steady motion is stable if the aircraft will return to that state of motion after disturbance without movement of the controls by the pilot.
Stagger	When main supporting surfaces are of equal chord, and when one such main supporting surface of a biplane or multiplane is in advance of another, these planes are said to be staggered. When the super-imposed main planes are of unequal chord the stagger must be specially defined. When the top main plane is forward, the stagger is said to be forward stagger. When the bottom main plane is forward, the stagger is said to be backward stagger.
Stalling speed	The air speed corresponding to the maximum lift co-efficient of an aeroplane. An aircraft is said to stall when its air speed drops below that necessary to support it in the air.
Starboard	The right-hand side as seen by the pilot looking forward. (*See* fig. 4.)
Streamline wire	A length of steel rod of approximately streamline section with ends left round and threaded. The ends of the wires are generally screwed into fork-ends, the thread being right-handed at one end and left-handed at the other. Adjustment is obtained by rotating the wire.
“ Stick ”	*See* “ Control column.”
Sump	A receptacle attached to the bottom of the lower half of the crankcase for collecting oil.
Tail unit	The combination of stabilising and controlling surfaces situated at the rear of an aeroplane. It consists normally of tail planes, elevators, rudder and tail fin. (*See* figs. 50, 57.)
Tail plane	The horizontal surface or surfaces forming part of the tail unit which affects the longitudinal stability of the motion of an aeroplane. (*See* fig. 57.).
Tail skid	A part of the alighting gear attached to the tail of an aeroplane, so arranged as to slide along the ground. (*See* fig. 50.)

Tail slide -	The rearward motion along its longitudinal axis which an aeroplane may be made to take after having been brought into a stalling position.
Taxying -	An aircraft is said to taxi when it moves under its own power in contact with the ground.
Thrust -	The force acting along the axis about which an airscrew is being rotated.
Time lag -	Time lag is the lapse of time between cause and effect. The time lag of an aeroplane control is the lapse of time between a well-marked phase in the movement of the control and the resulting reaction on the aeroplane.
Toggle -	A small cylindrical fitting secured at its middle point at right angles to a cord.
Torque -	The resistance of an airscrew to rotation. It is equivalent to the drag of an ordinary aerofoil and acts circumferentially owing to the rotation of the airscrew.
Trailing edge -	The after edge of a streamline body or aerofoil.
Turnbuckle -	A device for adjusting the length of a bracing wire. It consists of a metal barrel, into the ends of which are screwed right- and left-handed threads respectively. To adjust the turnbuckle it is only necessary to turn the barrel portion by means of a piece of stiff wire. (*See* fig. 88.)
Undercarriage	The part of an aeroplane intended for its support on land and to absorb the shock on landing. (*See* fig. 86.)
"Wash in" -	An expression used to denote an increasing angle of incidence towards the wing tip.
"Wash out" -	An expression used to denote a decreasing angle of incidence towards the wing tip.
Wing -	The word used in the science of aerodynamics to describe that portion of one of the main supporting surfaces of an aeroplane from the centre line of the aircraft to the wing tip.
Yaw, to -	To turn an aeroplane in the air about the normal axis. An aeroplane is said to yaw when the fore and aft axis turns to starboard or port, out of the line of flight. The angle of yaw is the angle between the fore and aft axis of the aeroplane and the instantaneous line of flight.

NOMENCLATURE OF AIRCRAFT.



CHAPTER I.—THE THEORY OF FLIGHT.

AERODYNAMIC FORCES.

Introduction.

1. Every pilot should have at least an elementary knowledge of the principles on which his aircraft works, how and why it flies and how it is controlled. To go at all deeply into the theory of aerodynamics requires considerable mathematical knowledge; but simple explanations can be given of most of the facts familiar to the pilot. It must be understood, however, that some of the explanations here given are necessarily brief and incomplete.

Aerodynamic forces.

2. Before the mechanics of the aeroplane can be considered, a clear idea of the quantities involved is necessary.

(i) *Force* may be defined as that which changes or tends to change the motion of a body, or causes or tends to cause motion in a body at rest.

(ii) *Pressure* is the force for each unit of area. It is very important not to confuse pressure with force.

(iii) *The moment of a force* is the turning effect of a force about a given axis, measured by the product of the force and the length of a line drawn from the axis of rotation perpendicular to the line of the force.

(iv) *Couples.*—Two equal and opposite forces, the lines of action of which are parallel but not coincident, are said to form a couple. A couple always tends to turn the body to which it is applied in the plane in which it acts.

3. If air flows past a body it exerts a force on it, and the size and direction of the force depends on the size and shape of the body and the velocity of the air flowing past it. The same principles of relative velocity apply if the body moves through the air. This force or reaction on the body is due partly to the deflection (*i.e.* change of motion) of the air round the body, and partly to the "stickiness" of the air itself, some of which tends to adhere to the body and drag it along. With aircraft this is called "skin friction." If the body is of irregular shape, such as a stone, the reaction on it is nearly in the same direction as the air flow; but if it is flat and held at a small angle to the air flow the reaction is nearly at right angles to the flat surface *i.e.* at an angle to the airflow. The wings which lift an aeroplane are designed so that when moved through the

air horizontally the force exerted on them by the air is as nearly vertical as possible, since it is this force that lifts the weight of the aeroplane.

Aerofoils.

4. It is found that the most suitable shape for causing a reaction at right angles, or nearly so, to the wind is not one in a flat plane, but one of a tapered section: a body of this shape is called an aerofoil. A few examples are given below, together with the purposes for which they would be used.

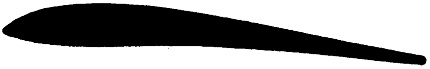


Fig. 6.

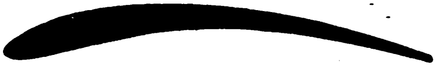


Fig. 7.

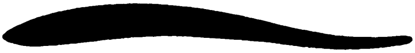


Fig. 8.

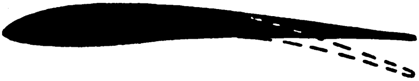


Fig. 9.

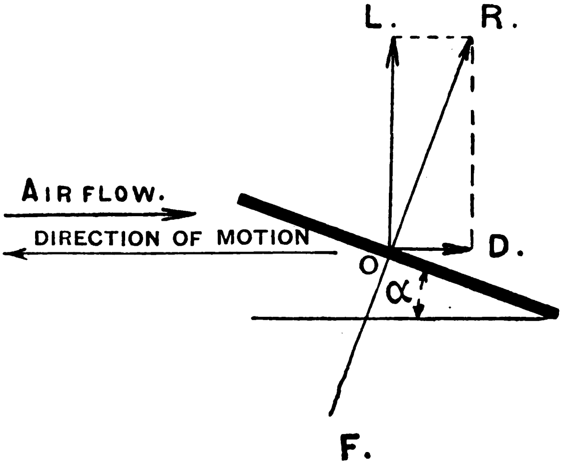


Fig. 10.

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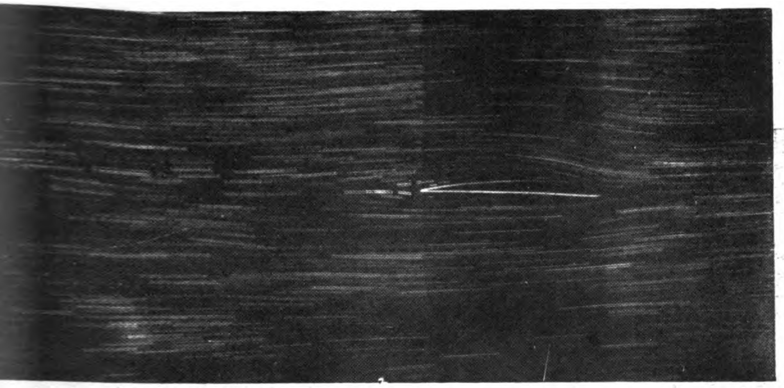


Fig. 11.—2°.

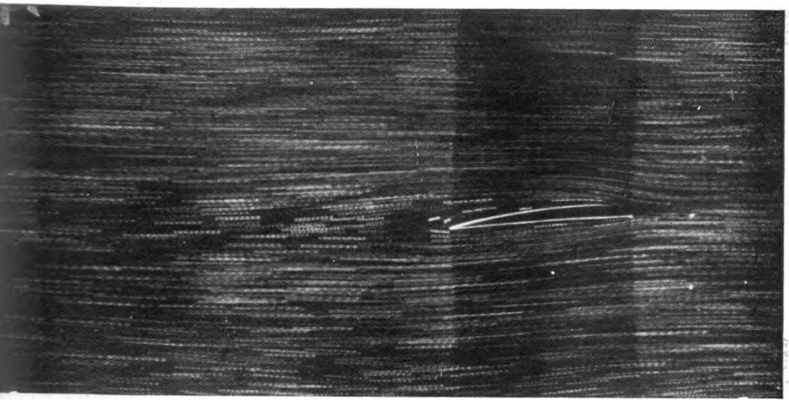


Fig. 12.—4°.

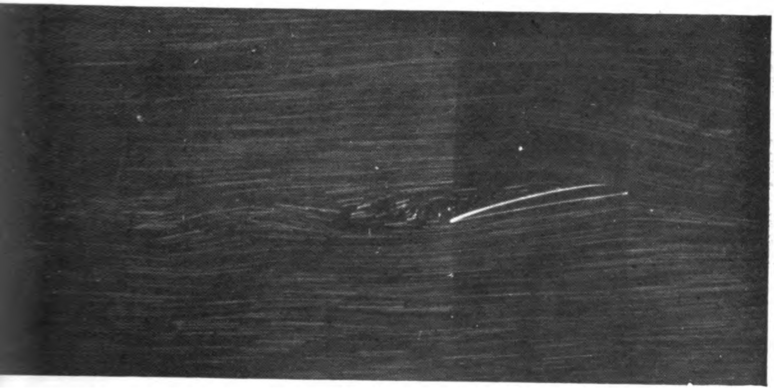


Fig. 13.—10°.

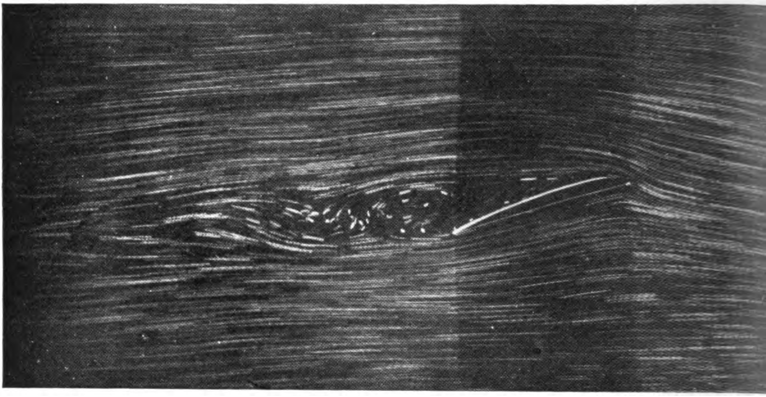


FIG. 14.—16°

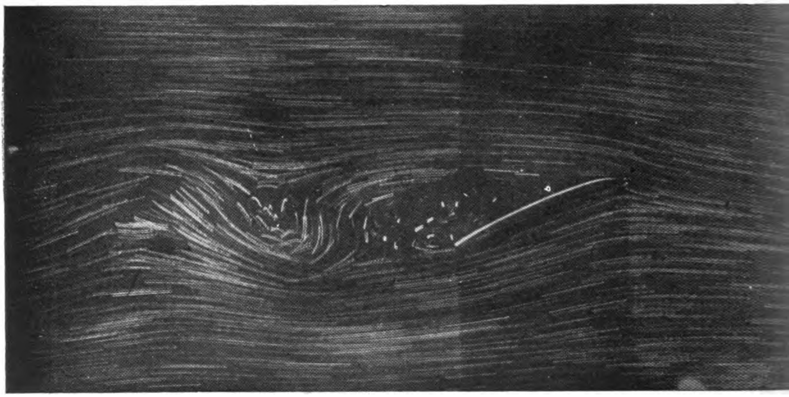


FIG. 15.—20°.

(i) *Fig.* 6.—Low cambered, low resistance aerofoil suitable for high speed single-seater aeroplane.

(ii) *Fig.* 7.—High cambered, high lift, low speed aerofoil suitable for load-carrying aeroplanes.

(iii) *Fig.* 8.—Aerofoil with upward curvature towards trailing edge, giving a decreased lift and an increased resistance but more stability fore and aft.

(iv) *Fig.* 9.—Variable camber aerofoil, embodying features of high flying speed and low landing speed.

Forces acting on an aerofoil.

5. In fig. 10 an aerofoil is represented as being pushed through the air in the direction shown by the arrow, *i.e.*, horizontally. The reaction will be roughly in the direction OR. By the elementary mechanical method known as the "parallelogram of forces" it is known that this force can be considered as being composed of two forces at right angles to one another, one vertical and the other horizontal. The vertical component will be called the lift (OL), as it is used to hold the aircraft in the air, and the horizontal component will be called the drag (OD). It is evident that the drag is a force directly opposed to the motion of the aerofoil, and as the work entailed in overcoming this force is performed by the engine in an aeroplane, the force must be as small as possible, or, as has been stated above, the reaction OR must be as nearly vertical as possible.

6. A perfect aerofoil, if it were possible to construct one, would be able to give a vertical lift and no drag. In a later paragraph it will be seen how the present forms of aerofoil are used to the best advantage.

Air flow round an aerofoil.

7. The way in which the forces on the aerofoil are set up is shown in figs. 11 to 15, which represent the flow of water containing oil drops (which is very similar to the flow of air) over an aerofoil.

8. It will be seen that the air is, as it were, "piled up" on the under-side of the aerofoil and forms eddies on the top, which become larger as the angle between the aerofoil and the wind becomes greater. The result of this is that there is an increase of pressure on the bottom of the aerofoil and a reduction of pressure on the top, the difference being greater on the top.

Variation of lift with incidence.

9. Figs. 11 to 15 show that as the angle between the aerofoil and the wind increases, the eddies on the top of

the former become more violent, and, as may be expected, the total force on the aerofoil increases. In order to compare the forces at different angles, two more definitions are needed :—

(i) *Chord.*—The straight line (taken conventionally fore and aft, unless otherwise specified) touching the concave surface of an aerofoil at or near the leading and trailing edges.

(ii) *Angle of incidence.*—The angle between the chord of the aerofoil and the direction of the air-flow past it (taken as positive when the convex surface of the aerofoil is on the opposite side of the chord from the line representing the air flow).

10. In some ways it might be more convenient to define the angle of incidence in such a way that no lift occurs at zero incidence, but for practical purposes the above definition is more satisfactory, the lift vanishing at about — 2 to — 4 degrees according to the type of the aerofoil.

11. Fig. 16 shows how the lift component of the reaction varies with incidence. It will be seen that a maximum value is reached at 15° incidence, after which it rapidly falls. This is commonly referred to as the " stalling point."

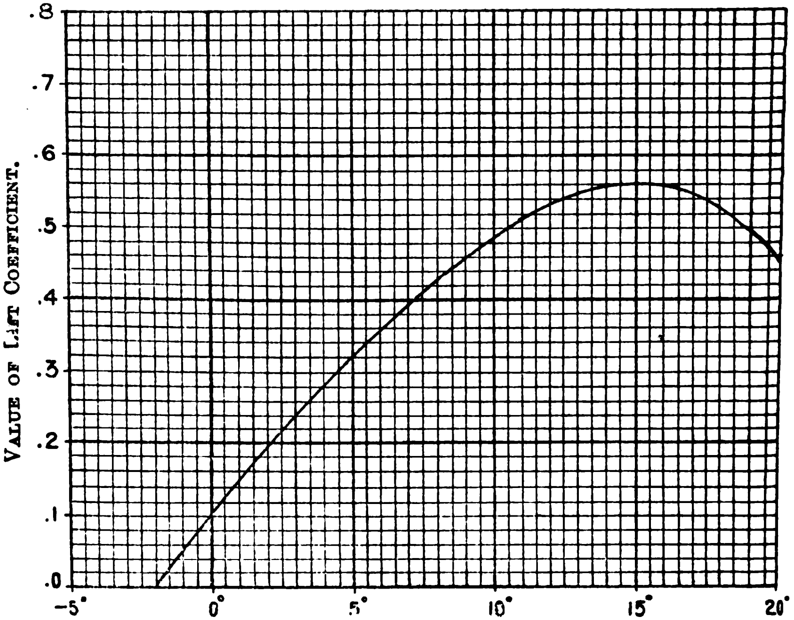


FIG. 16.—Angle of Incidence (Degrees).

In the same way the drag component increases from about ½° incidence, but grows more rapidly as the incidence increases. This is shown in the next curve (fig. 17).

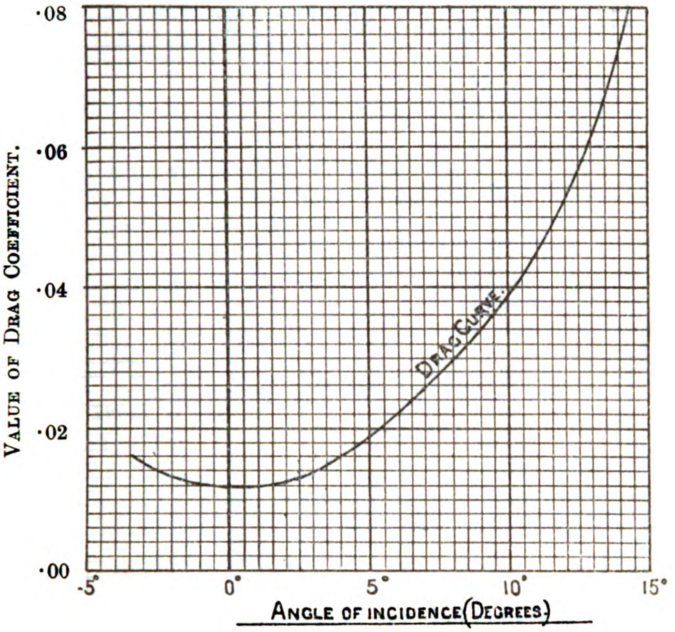


Fig. 17.

Thus, although it is desirable to obtain as much lift as possible from the aerofoil, this cannot be done without increasing the drag, and it is necessary to find the best compromise. The total lift is fixed by the weight of the aeroplane; but if the reaction on the aerofoils is made as nearly as possible perpendicular to the air flow the drag will be as small as possible.

12. The ratio of the lift to the drag is referred to as the L/D ratio, and its variation with incidence is shown in fig. 18.

From this it will be seen that to obtain a given lift with as small an expenditure of energy as possible in overcoming drag, the aerofoils must be set at the angle corresponding to the greatest value of L/D for the aerofoil for which this curve was taken; this occurs at about + 4½°.

Lift and drag co-efficients.

13. The lift and drag on an aerofoil depend not only on the angle of incidence, but on the velocity of the air-stream

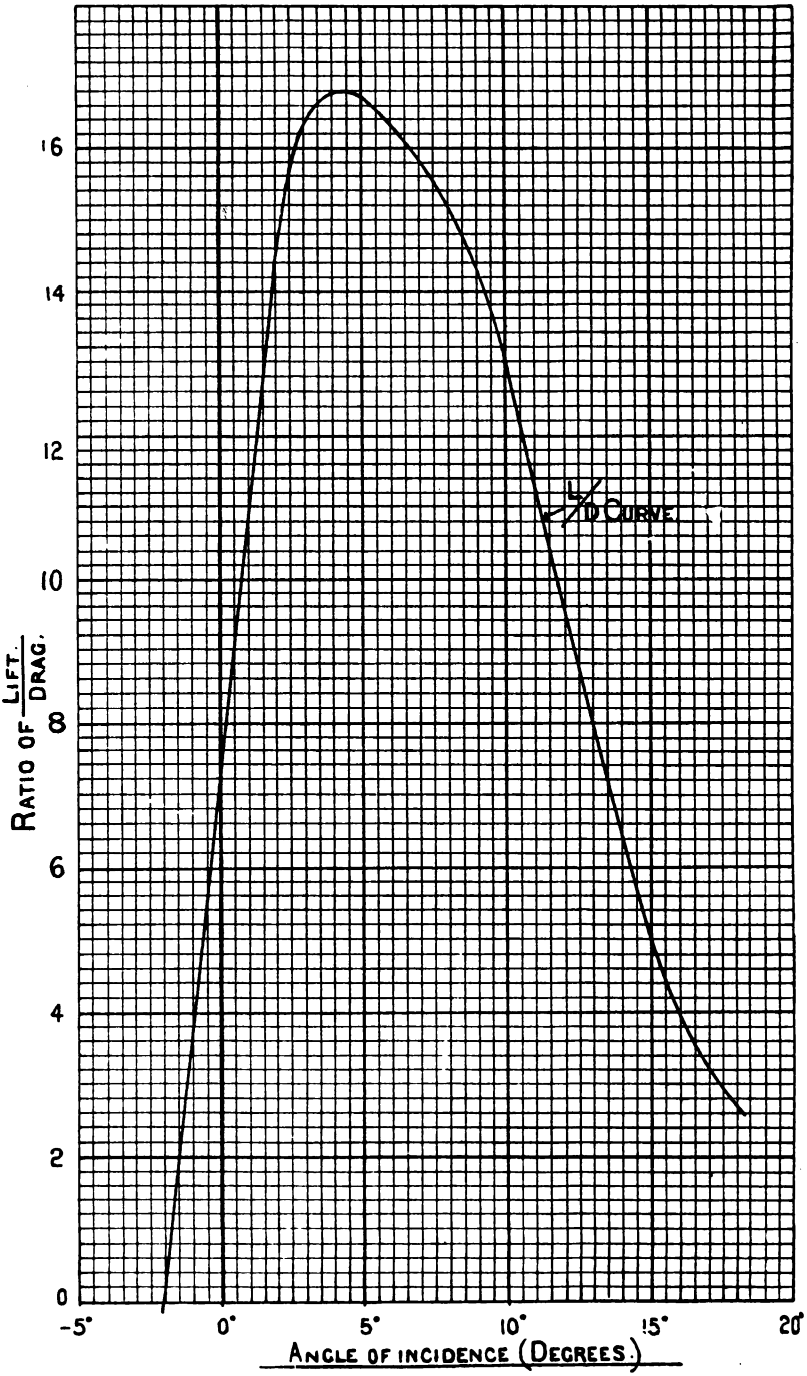

16
14
12
10
8
6
4
2
0
Ratio of $\frac{\text{Lift}}{\text{Drag}}$
L/D Curve
-5°
0°
5°
10°
15°
20°
Angle of incidence (Degrees)

Fig. 18.

and the density of the air. For a given aerofoil of area S in a given velocity V of air of a density π the lift is given approximately by

$$L = K_L \pi S V^2$$

where K_L is a constant depending on the angle of incidence. Similarly the drag is given by

$$D = K_0 \pi S V^2$$

The constants K_L and K_0 are called the lift and drag coefficients, respectively.

14. Thus it will be seen that a given lift can be obtained with a large velocity and a small angle of incidence, or with a small velocity and large incidence up to the angle corresponding to the maximum lift (*i.e.* stalling angle).

15. This angle of maximum lift corresponds to a certain minimum air speed; if the speed of an aeroplane is allowed to fall below this minimum, the lift cannot be maintained by increasing the incidence further, but will lessen and the aeroplane will fall. This is called " stalling."

Streamline bodies.

16. A body is said to be streamlined when it is so designed that its resistance to air-flow is the minimum (compatible with other conditions) for its size. All parts of an aeroplane are streamlined as far as possible.

CONTROLLING SURFACES.

Arrangement of surfaces on an aeroplane.

17. The ordinary type of aeroplane is composed of wings (aerofoils) to give the necessary lift; a body (fuselage) to hold the pilot, crew, bombs, guns, etc.; an engine and airscrew to propel it through the air; and certain subsidiary aerofoils fitted to provide stability and control.

18. The wings are fitted so that the force of lift derived from the whole system (if there is more than one plane) acts very nearly through the centre of gravity of the aeroplane. Otherwise a strong couple would be introduced tending to rotate the aeroplane in another direction, which would have to be resisted by the controlling surfaces. The lift is composed of the resolved components of an infinite number of small forces acting at all points of the surface. If these are combined and considered as equivalent to a single force, the point where the line of action of this force cuts an arbitrarily chosen surface in the aerofoil or system of aerofoils is known as the " centre of pressure." This point will be frequently referred to in considering forces on an aerofoil.

19. For a given aerofoil the distance of the centre of pressure from the leading edge depends on the angle of incidence employed. For a flat plane, as the angle of incidence is decreased, the centre of pressure moves towards the leading edge; but with an aerofoil, the section of which is curved (with respect to the direction of flow), and the concave side of which is taking the positive pressure exerted by the airflow, the centre of pressure moves towards the trailing edge as the angle of incidence is decreased.

Function of the tail-plane.

20. The variation of the centre of pressure (C. of P.) of the main planes causes the aeroplane to be unstable. If, owing to some disturbance, the incidence is increased temporarily, the C. of P. moves forward, and introduces a couple which tends to turn the aeroplane in a direction which still further increases the incidence by depressing the tail. Similarly if the incidence is momentarily reduced, the travel of the C. of P. backwards will tend to reduce the incidence still further, and cause the aeroplane to dive. To overcome this and to give stability, a small subsidiary aerofoil is added some distance behind the centre of gravity (C. of G.) of the aeroplane. If this is set so that normally it has no lift it will, when the C. of P. moves forward through increase in incidence, possess some incidence itself, and so give rise to a lifting force behind the C. of G. that will tend to right the aeroplane. This plane is fitted in the position shown in fig. 19 and is called the tail-plane.

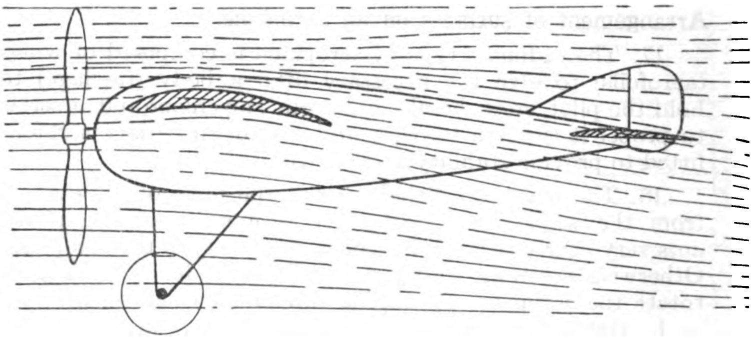


Fig. 19.

The axes of an aeroplane.

21. The fixed axes of an aeroplane are as follow :—

(i) *The longitudinal axis* is a straight line in the plane of symmetry through the centre of gravity, measured fore and aft. In general theoretical discussions of the motion of an aeroplane, this may be taken as parallel to the airscrew axis. An angular motion about the longitudinal axis is called "rolling." A complete turn about this axis takes place during a roll; but it should be noted that in this manœuvre the rotation is not uniform and has components about other axes.

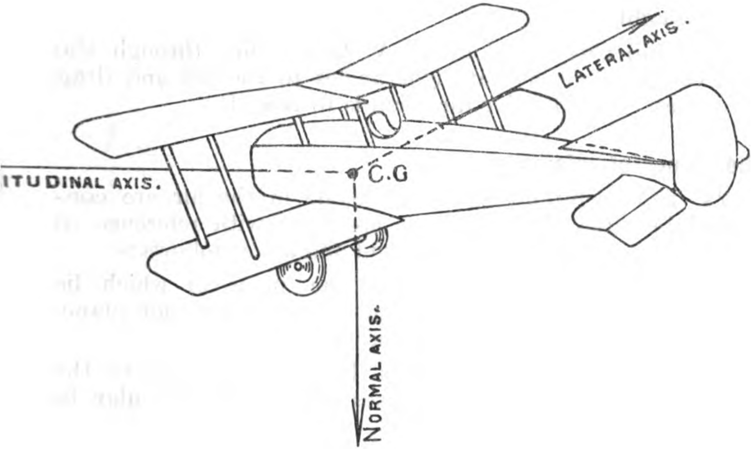


FIG 20.

(ii) *The normal axis* is a straight line through the centre of gravity in the plane of symmetry at right angles to the longitudinal axis as defined in (i) above. Angular motion about the normal axis is called "yawing."

(iii) *The lateral axis* is a straight line through the centre of gravity normal to the plane of symmetry. The lateral axis may be taken as parallel to the line joining the wing tips, and, when regarded from the direction of motion, the positive branch of the axis is to starboard. An angular motion about the lateral axis of an aeroplane is termed "pitching."

22. When the longitudinal and lateral axes are horizontal, the normal axis is vertical. A complete revolution about the lateral axis is called a loop. The loop commonly practised is in the positive direction of rotation; a negative loop beginning downwards has, so far as is known, never been accomplished.

23. Axes that change direction with change of attitude of aircraft are :—

(i) *The drag axis.*—A straight line which passes through the centre of gravity, and is parallel to the direction of wind (air flow).

(ii) *The lift axis.*—A straight line which passes through the centre of gravity, is in the plane of symmetry, and is perpendicular to direction of the wind. The positive direction is upwards in ordinary straight flight.

(iii) *Cross wind axis.*—A straight line through the centre of gravity at right angles to the lift and drag axes. The positive direction is to the left.

The planes of reference.

24. The evolutions of an aeroplane in the air are considered in three planes. These are fixed with reference to the aeroplane and not to the ground and are as follows :—

(i) *The yawing plane* is the plane in which lie the longitudinal and lateral axes of the aeroplane. It is perpendicular to the normal axis.

(ii) *The looping plane* is the plane in which lie the longitudinal and normal axes. It is perpendicular to the lateral axis.

(iii) *The rolling plane* is the plane in which lie the lateral and normal axes. It is perpendicular to the longitudinal axis.

Functions of the tail-plane and elevator.

25. If a tail-plane be constructed of symmetrical form about a centre line passing through its front and rear spars, (*see* fig. 21), of section which has equal camber on both surfaces; if it is fitted with an elevator which is likewise symmetrical and in prolongation of the tail-plane; and if the centre line is parallel to the air flow: then the angle of incidence will be 0°. The tail-plane will deflect the air flow equally above and below it, so that there will be no resultant component force perpendicular to the air flow. If the tail-plane with its elevator still in true prolongation be set at an angle of incidence to the air flow, a component force perpendicular to the air flow will be produced which will act in a positive or negative direction according to whether the angle of incidence of the tail-plane is negative or positive. (*See* figs. 21, 22, 23 and 24.)

26. The elevator is hinged to the rear spar of the tail-plane, and can be moved through an arc about its hinge. Its

action is such that in effect the camber of the tail-plane and elevator combined is varied through a certain range

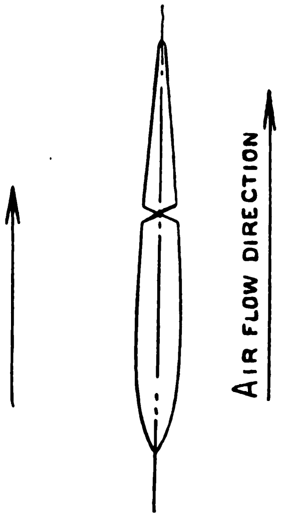


FIG. 21.

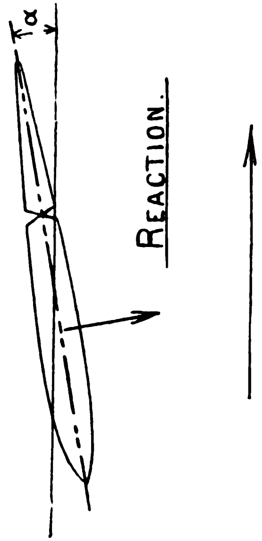


FIG. 22.

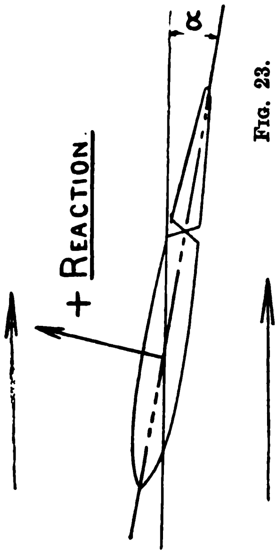


FIG. 23.

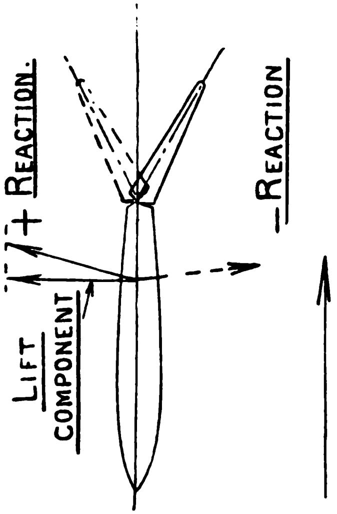


FIG. 24.

(*see* fig. 24). When the tail-plane and elevator are set so as to give no perpendicular component force, as described above; and the elevator is depressed independently of the tail-plane, so that the elevator gives a virtual camber and incidence to the tail-plane and elevator considered as a whole; then this virtual camber and incidence give a deflection to the air flow and cause the reaction to have a perpendicular component as shown in fig. 24. This force is utilised to produce an additional couple about the centre of gravity, and the consequent desired rotation of the aeroplane about the lateral axis.

27. The centre of pressure of the wing surfaces varies in position. This movement of the centre of pressure sets up a varying couple about the centre of gravity which tends to rotate an aeroplane about the lateral axis. The function of the tail-plane is to set up a counteracting couple about the centre of gravity. In virtue of this counteracting couple, (set up by the action of the air flow over the tail-plane and elevators), the pitching of the aeroplane is under control of the pilot as he varies the virtual camber of the tail-plane and elevator surfaces by altering the setting ot the elevators. Fig. 19 shows diagrammatically the flow of air over the tail-plane after deflection by the main planes. With a variable tail-plane the range of control may be altered, and a desired fore-and-aft trim can be maintained without constant pressure on the elevators.

28. The centre of pressure of reaction on the tail-plane also varies in position, but the alteration of the moment about the centre of gravity which is set up is so small compared with the change of the moment about the centre of gravity caused by the controlling moments at the pilot's disposal, that it may be left out of consideration.

Functions of the ailerons.

29. The ailerons are the control surfaces placed on the outer extremities and usually the trailing edges of the wings. When on the trailing edges of the wings they form part of the main lifting surfaces, and, being hinged to a suitable spar in the wings, they may be moved by the pilot through an arc of about 20° from either side of true prolongation of the wing surfaces. The effect of setting the ailerons other than in the normal position is to increase or decrease the effective camber of those parts of the wing to which they are attached. This gives an increase or decrease of lift from the air flow reaction.

30. The ailerons on opposite wings are interconnected so that if the ailerons on one side be depressed, thereby giving an increase in virtual (*i.e.*, effective) camber to that wing, the aileron on the other side is elevated, thereby causing a decrease in virtual camber. The difference in the air-flow reactions on the opposite wing extremities sets up a couple tending to roll or rotate an aeroplane about the longitudinal

axis. For small flying incidence the decrease of lift at one wing tip is nearly compensated by increase of lift at the other wing tip, and the total lift is thus not appreciably reduced.

31. A secondary effect of this difference in virtual camber is a tendency for the aeroplane to yaw about her normal axis. This tendency is due to the increase of resistance at the wing tip where the aileron is depressed, accompanied by a decrease in the resistance at the opposite wing tip where the aileron has moved up into a more streamlined position; it is known as "aileron drag" and can be counteracted by the use of the rudder.

32. In straight flight, when the incidence of the wings is such that the critical angle is reached when the aeroplane is at stalling point; if the virtual camber on the wing on one side be increased by depressing the aileron, that part of the wing will definitely exceed the critical angle. This results in a loss of lift at both wing tips at the same time, and the aeroplane may start to lose height in a manner characteristic of stalling. Further, the drag increases very rapidly when the critical angle is exceeded, and the yawing tendency mentioned in the previous paragraphs will, therefore, become very strong. The application of rudder increases the stall and it may result in a yawing motion towards the wing of which the aileron has been depressed, thus reducing the speed of this wing tip, while the opposite wing tip travels faster; the slower moving wing will have less lift than the other, and the aeroplane will drop the wing tip of which the aileron has been depressed. Thus the use of the aileron at an air speed near the stalling speed may produce a reverse effect to that produced in ordinary flight and may cause loss of control.

33. When endeavouring to turn an aeroplane whilst taxying, the pilot is assisted by the additional drag produced on the depressed aileron side, which tends to swing the aeroplane in the required direction.

Functions of rudder and fin.

34. The rudder is a controlling surface which normally lies in the looping plane (*i.e.*, the vertical plane when the aeroplane is horizontal on an even keel). It is usually situated at the extreme rear of the fuselage. It is hinged about the stern post, which is generally parallel to the normal axis, and can be moved by the pilot through an arc of about 30° on either side of its normal position. When used in conjunction with a fixed fin it has a similar effect aerodynamically to that of a variable camber aerofoil.

35. The reaction force induced by the operation of the rudder sets up a movement in the yawing plane which tends to turn an aeroplane about its normal axis. This movement is known as "yawing." Where no fin is employed, the effect is very similar. The part of the rudder which rises clear of much interference from the fuselage approaches the condition of a flat plane in the air-flow, and its incidence can be varied within limits.

Balanced controls.

36. All control surfaces may be partly balanced so that the force to be exerted by the pilot in operating them is reduced considerably as compared with unbalanced controls. Balanced controls are usually found to be necessary on very large aeroplanes.

Stagger of main planes.

37. When the main supporting surfaces (*i.e.,* planes) of an aeroplane are of equal chord, and when one such plane of a biplane or multiplane is in advance of another when the aeroplane is in rigging position, these planes are said to be staggered. When the top main plane is forward, the stagger is said to be forward stagger. When the bottom main plane is forward the stagger is said to be backward stagger. The disposition in this way of the main planes of a biplane or multiplane is chiefly determined by the requirements in design.

Gap.

38. Gap is the distance between the top and bottom main planes of a biplane or the distance between any two superimposed planes in a multiplane, measured from chord to chord. The air-flow surrounding the moving plane is deflected to some considerable distance above and below the surfaces. It has been found experimentally that the gap should not be less than a certain ratio of the chord, in order that the effective action of one plane may not be interfered with by the other plane.

The dihedral angle.

39. In geometry the angle between two planes is called a dihedral angle. The planes of an aeroplane are said to be at a positive dihedral angle when starboard and port main planes are upwardly inclined to the lateral axis (*see* fig. 25).

When downwardly inclined, they are said to be at a negative dihedral angle (*see* fig. 26).

40. The lift value of the main planes is slightly lessened by the dihedral, because the lift force for each wing is perpendicular to the wing. For example, when the aeroplane

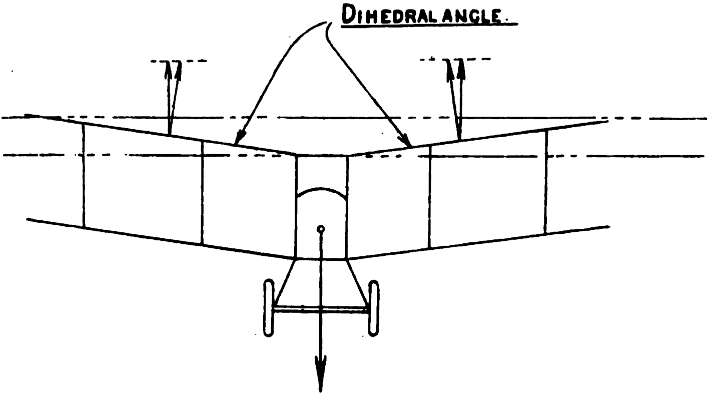


FIG. 25.

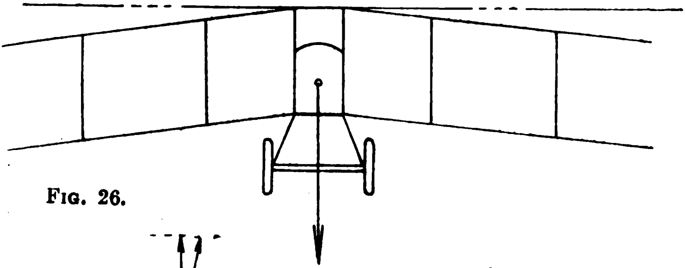


FIG. 26.

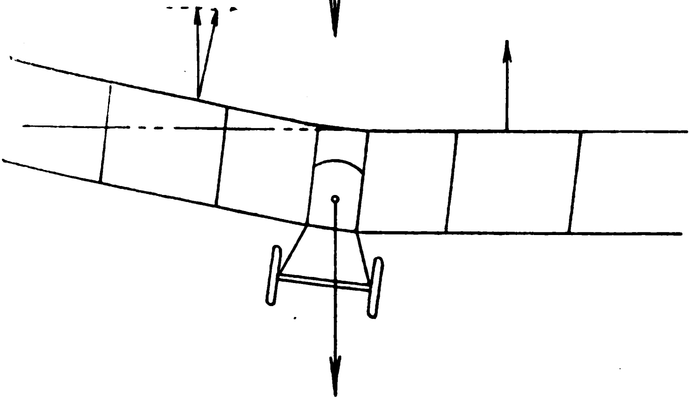


FIG. 27.

is flying level, only the vertical components of these lifts act against gravity. The dihedral is employed, however, because it sets up a restoring couple in an aeroplane which rolls slightly, and thus gives a natural stability. When the aeroplane is banked, it begins to sideslip towards the lower wing, which, meeting the air at a greater angle than the upper wing, has a temporary increase of lift. This lift restores it to the normal flying position. An aeroplane with dihedral has a natural tendency to check a skid or sideslip (*see* fig. 27).

41. Negative dihedral has the reverse effect in rolling to that of positive dihedral. The setting up of a restoring moment is one of the many conditions that must be satisfied for stability. Negative dihedral is sometimes incorrectly spoken of as " anhedral."

Equilibrium.

42. If a body is subjected to a force or number of forces, its state of motion will generally be changed; but if these forces are such that their magnitude and lines of action satisfy certain conditions, they will balance one another, and thus cause no change in the motion of the body. The body is then said to be " in equilibrium." It must be clearly understood that equilibrium does not necessarily imply a state of rest, but simply one of unchanging velocity; that velocity may or may not be zero.

43. A change in velocity may be a change in either speed or direction, or both; and a body is only in equilibrium if both its speed and direction of motion are not changing. To produce a change of either kind, a force must be applied. For example, if a body moving uniformly in a straight line is to be brought to rest, a force must be applied in the opposite direction to that of its motion. If a stone tied to the end of a string be whirled round in a circle at a constant rate, its velocity is continually changing in direction, and requires the application of an appropriate force, namely, the tension of the string. If the string breaks the force ceases to act; the stone stops its circular movement and goes off in a straight line.

44. A body in equilibrium, and acted on by forces which, if it is disturbed slightly, tend to bring it back to its original position is said to be in "stable equilibrium." If the condition of the body is such that any change in its position, however slight, causes the forces acting on it to increase the movement until some new and entirely different position of equilibrium is reached, the body is then said to be in " unstable equilibrium."

LEVEL FLIGHT.

Forces acting on an aeroplane in uniform level flight.

45.—(i) With a given setting of all lifting and control surfaces, and with a uniform thrust and symmetrical distribution of weight, an aeroplane flying horizontally through still air of uniform density is in equilibrium under the influence of three easily distinguishable groups of forces repre-

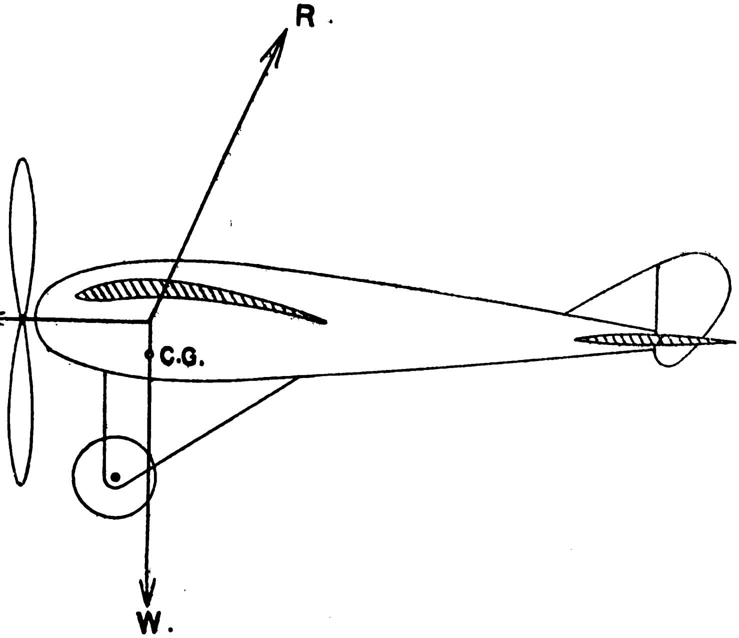


FIG. 28.

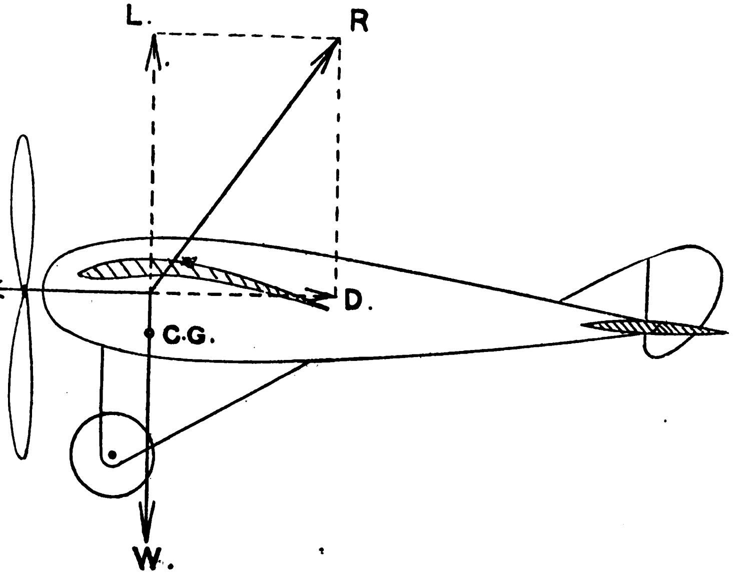


FIG. 29.

sented by their resultants, as shown in fig. 28. T represents the total thrust of the airscrew, *i.e.*, the resultant of the air forces on the blades. For simplicity, it is assumed that the line of thrust is parallel to the horizontal flight path. W represents the total weight of the aeroplane, *i.e.*, the resultant of the gravity forces acting vertically through the centre of gravity. R represents the total aerodynamic reaction on the exposed surfaces of the aeroplane. These forces act in the plane of symmetry.

(ii) The vertical component of R is perpendicular to the horizontal line of flight, and is identical with the lift L, which for equilibrium must be equal and opposite to W (*see* fig. 29). The horizontal component of R is parallel to the line of flight, and is identical with the total drag D, which for equilibrium must be equal and opposite to the thrust T (*see* fig. 29) The line of action of R is fixed by the third condition that the lines of action of W, T and R must meet in a point.

Slipstream of an airscrew.

46.—(i) The airscrew propels the aeroplane through the air in the same way that the wings produce the lift, *i.e.*, by displacing the air in a direction perpendicular to the direction of its motion. The result of this is that the air immediately behind the airscrew is pushed backwards in relation to the surrounding air and is also given a corkscrew motion, as shown in fig. 30.

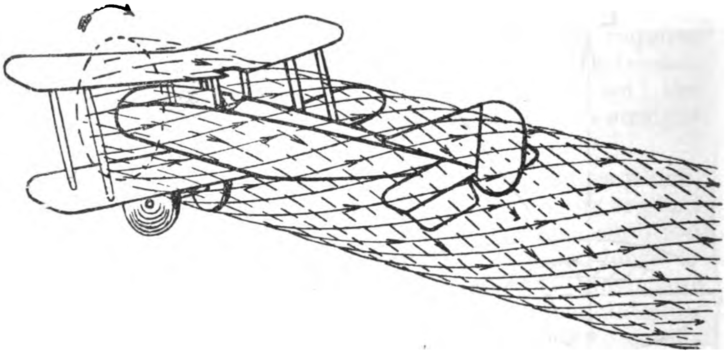


Fig. 30.

Thus the air speed over the tail plane and rudder is greater than that of the forward speed of the aeroplane as a whole. When the engine is running, this increases the effect of these units to an extent which varies according to the speed of the rotation of the airscrew.

(ii) The axis of the corkscrew motion imparted to the air is below the centre of pressure of the fin surface of the after part of the aeroplane (*see* definition of fin-surface), with the result that the pressure is increased on one side of the tail unit and decreased on the other, and a yawing tendency is produced. This may be counteracted either by a slight movement of the rudder by the pilot or by a permanent offsetting of the fin, if one is fitted.

Airscrew torque.

47. Just as it is impossible to obtain lift from a main plane without experiencing drag, so thrust cannot be obtained from an airscrew without overcoming a couple tending to resist its motion through the air. The reaction due to this couple is termed " airscrew torque," and it tends to tilt the aeroplane in the rolling plane in the opposite direction to that in which the airscrew is revolving. It is usually compensated by giving one wing a slightly greater incidence than the other, thus setting up a couple in the opposite direction.

Airscrew slip.

48. The ratio of the difference between the forward speed of an aeroplane and the forward speed which is necessary for the airscrew to give a zero thrust (*i.e.*, no thrust) is called the airscrew slip (the airscrew is considered to be rotating at the same number of revolutions in each instance).

Equilibrium of an aeroplane at different speeds.

49. In the following consideration of the behaviour of an aeroplane in the air, it will be assumed that the effects of slipstream and torque have been corrected in the manner indicated, and they will be neglected. For pitch of an airscrew, *see* definitions, page xv.

50.—(i) Within the normal flying range of speed, if the engine is opened up, the aeroplane commences to climb. The reason is that the increased thrust of the airscrew accelerates the aeroplane along the longitudinal axis, and this extra speed increases the lift on the main planes until a new condition of equilibrium is attained, in which the flight path of the aeroplane will be slightly inclined to the horizontal. This has the effect of reducing the actual angle of incidence to such an extent that, at the higher speed, the lift is again equal to the weight of the aeroplane.

(ii) In order to regain level flight, it will be necessary for the pilot first to push the control column forward to reduce the incidence; then, when the aeroplane is again flying horizontally, to pull back the control column very slightly in order to remove the couple which has changed the position of the aeroplane from climb to level flight. When level flight is once more attained, but at a higher speed, the

the aeroplane is flying nose down at a smaller angle of incidence (*see* fig. 31).

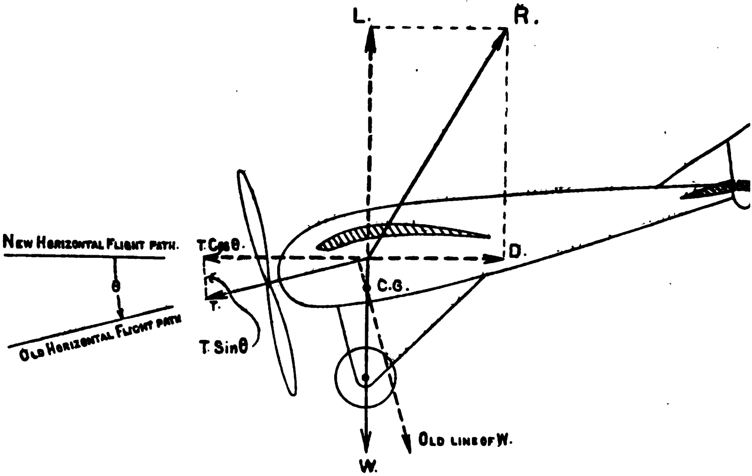


Fig. 31.

51.—(i) In fig. 31 the angle of inclination θ of an aeroplane to the horizontal flight path is shown greatly exaggerated for the purpose of the illustration. The thrust may be assumed to be horizontal, as the small vertical component of the thrust merely produces a corresponding small change in the effective lift. In this position, the control column will be slightly forward of the original position, the reason being that when the angle of incidence is reduced the centre of pressure moves backward and introduces a couple tending to put the nose still further down. This couple is normally counteracted by the effect of the tail-plane (*see* para. 20), which tends to return the aeroplane to its original position, and this correcting effect must be removed by the elevator.

(ii) If, instead of increasing the speed, it is desired to climb at the same speed, then, when the engine is opened out, the control column is first pulled back, in order to increase the incidence and to introduce a couple necessary to turn the nose up; when the required climbing angle is attained, the control is eased forward slightly in order to restore equilibrium in straight and uniform, but upwardly inclined, flight. In the final climbing position the incidence will be the same as before, if the speed is the same, since the lift is still equal to the weight of the aeroplane, and this lift depends on incidence and speed.

52. The angle of climb is limited by the power available from the engine; when the aeroplane is climbing, the engine,

n addition to overcoming drag, has to do work in lifting the aeroplane, and this rate of lifting is limited by the extra power available. When climbing at constant speed the aeroplane is in equilibrium, and if the angle of climb is small, no more lift is required than for normal flight. If, however, the angle of climb is so great that the lift on the planes is appreciably out of the vertical, only a portion of this lift is available for supporting the weight of the aeroplane, and the lift must, therefore, be increased by enlarging the angle of incidence.

53. An aeroplane with an adjustable tail plane can be set to fly in any position with a fixed throttle opening, a definite adjustment of the tail-plane being necessary for equilibrium with any particular angle of incidence.

54. On certain types of aeroplane the axis of the airscrew is set some distance from the centre of gravity, and in such types every variation in airscrew thrust will give rise to a couple tending to turn the aeroplane in the pitching plane, which tendency must be counteracted by a movement of the controls or the adjustable tail-plane. In some aeroplanes this effect completely overshadows the effect of the movement of the centre of pressure.

Effect of additional engine power.

55. An aeroplane will fly at uniform speed at one definite angle of incidence so long as the density of the air, the total weight of the aeroplane, and the thrust all remain constant. If the engine power be augmented the speed will rise to such an extent that the increased resistance will balance the increased thrust. In order to maintain level flight, the angle of incidence of the lifting surfaces will have to be decreased so that the total lift remains the same throughout the change of speed.

56. It will be seen that with the maximum power available, the aeroplane will have a maximum air speed in flight depending upon the drag of the aeroplane at the maximum speed, the weight or loading, and the density of the air. If a curve be drawn, as shown in fig. 32, by plotting the value of the horse-power required for level flight, against the respective level speeds, and if a second curve be drawn by plotting the horse-power available against the corresponding air speeds at which it can be developed, then the length of any vertical line between these two curves will be a measure of the excess horse-power which is available for climbing at the speed shown on the diagram. The best rate of climb will be obtained where the length of the vertical line is the greatest (*see* hc on fig. 32). The maximum level speed will be attained where the power required for level flight is equal

to the horse-power available shown by the intersection of the curves where marked "Max." in fig. 32. The intersection of the curves at the point marked "Min." denotes the minimum flying speed.

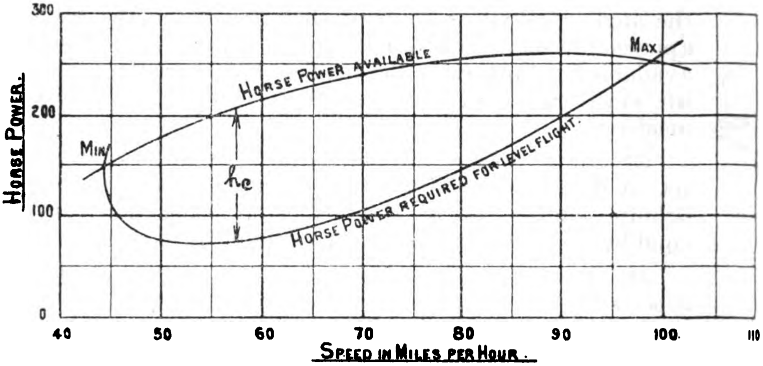


Fig. 32.

Gliding.

57. In level flight the power required to overcome the drag of the aeroplane is provided by the engine; but if the engine is stopped, the flight path must be changed so that the weight of the aeroplane has a component in the direction of flight, gravity then providing the necessary power. The aeroplane is then said to be gliding, and the angle that the flight path makes with the horizontal is known as the "gliding angle."

58. Neglecting the very small airscrew thrust produced by an engine "ticking over," there are under these conditions two forces only acting on the aeroplane, *viz.*, its weight and the total air reaction, represented by OW and OR in fig. 33. In order to maintain equilibrium, these must act in opposite directions along the same line, *i.e.*, the vertical through the centre of gravity of the aeroplane. In gliding flight the pilot so adjusts his controls that these conditions are satisfied while the attitude of the aeroplane in relation to the earth is such that the component of gravity along the flight path is great enough to push it through the air at the speed necessary to maintain flight.

59. It will be seen that the whole air reaction now balances the weight of the aeroplane and not only a component, so that the "lift" required is actually slightly less than in level flight. The angle between the line of reaction OR and the lift axis OL is the same as in level flight at the same speed and incidence, and, since OR is vertical, it is equal to the gliding

angle. We have already seen that a small angle LOR corresponds to a high L/D ratio, so that in order to have a small gliding angle, the aeroplane must be flown at such a speed and incidence that the L/D ratio is at the maximum that is consistent with obtaining the necessary lift.

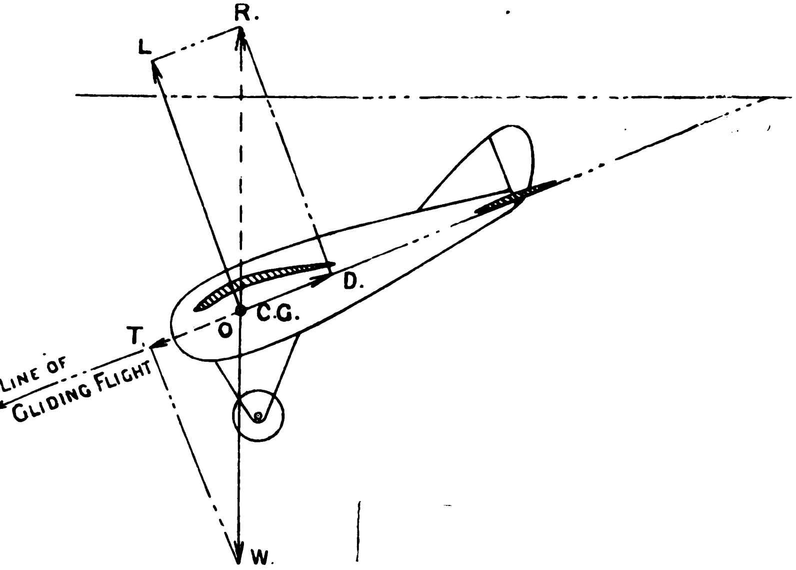


FIG. 33.

Best gliding angle.

60.—(i) As a small gliding angle gives a large choice of landing point in the event of fuel or engine failure, the minimum gliding angle is called the "best gliding angle"; in most modern types of aeroplanes this is between 1 in 7 and 1 in 10, *i.e.*, the aeroplane glides 7 to 10 feet horizontally for every vertical drop through one foot.

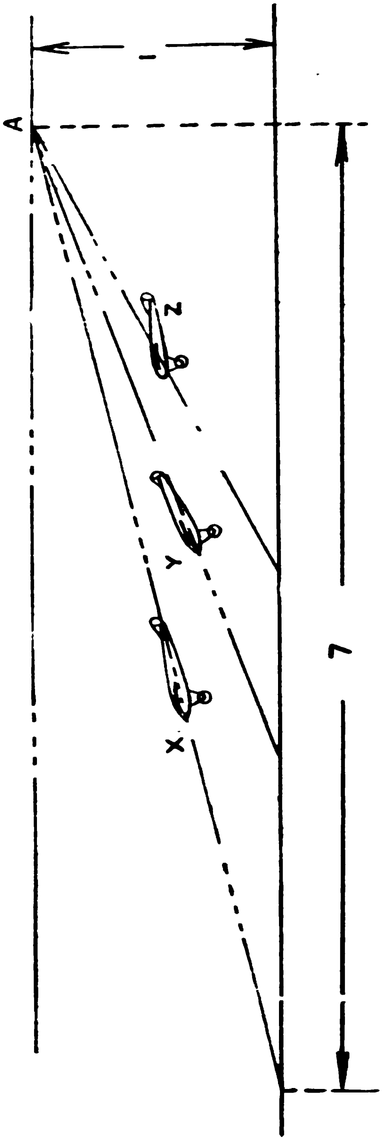
(ii) If an aeroplane starts at A (*see* fig. 34), and the pilot increases the speed, the aeroplane will dive steeply toward the ground as at AY. If, on the other hand, he reduces the speed too much, the necessary angle of incidence will be so large that the flight path will have to be steeply inclined, and the aeroplane will "pancake" to earth as at AZ. Between these two extremes lies the best gliding angle AX.

TURNING.

Gyroscopic action.

61. The forces acting on the aeroplane during straight flight have been considered, but there is another force which

comes into play when an aeroplane is changing direction. This is gyroscopic action.



X Represents gliding flight path at smallest gliding angle.
Y ,, ,, ,, ,, ,, speed greater than best flying speed.
Z ,, ,, ,, ,, ,, ,, lower ,, ,, ,, ,,

Fig. 34.

62. If a heavy body is rotating about a certain axis (which will be called the axis of rotation), and this axis be turned

about another axis at right angles to it (which will be called the turning axis), the body will tend to turn about an axis at right angles to them both. If this motion (known mathematically as "precession") is to be prevented, a definite couple must be introduced in the reverse direction, its moment depending on the "moment of inertia" of the rotating body, the angular velocities about the axis of rotation, and the turning axis. It is impossible to give a more detailed explanation without introducing somewhat advanced mathematics, and it must suffice merely to state the fact and its effect on the flight of an aeroplane.

63. If an aeroplane, fitted with a rotary engine revolving in a right-handed direction as seen by the pilot, is turned to the right, the nose will tend to go down, and rudder or elevator (according to the angle of bank) must be applied to keep it up. In this example the engine is a heavy body rotating about the longitudinal axis of the aeroplane, and this axis is being turned about a vertical axis. The resultant precession is about a horizontal axis perpendicular to them both.

64. The effect is the same in types of aeroplanes with stationary engines, owing to the gyroscopic action of the airscrew, but it is not nearly so great. In an aeroplane with a large rotating engine, full left rudder is necessary on a steep turn and in a loop, owing to the strong gyroscopic action set up by the movement of the aeroplane in the looping plane.

Forces acting on an aeroplane while turning.

65. It has been explained in para. 42 that an aeroplane is in equilibrium while flying in a straight line at uniform speed. To make an aeroplane turn, therefore, a force must be applied which, if the path of the aeroplane is a circle, must be directed towards the centre of the circle. In order to impose this force on an aeroplane, the total air reaction must be inclined to the vertical, so that its horizontal component just provides the force necessary to keep an aeroplane turning in a circle of the desired radius. This force is known as the "centripetal force."

66. In the correct turn the inclination of the reaction is produced by banking the aeroplane as shown in fig. 35. OW represents the weight of the aeroplane, and OL the component of the reaction acting in the rolling plane. This is vertical in straight flight, but is now inclined to the vertical at an angle θ, normally equal to the angle of bank. The vertical component (OA) of OL balances the weight of the aeroplane, while the horizontal component (OC) provides the necessary centripetal force. This is true whatever the angle of bank, but in order to turn with no sideways move-

ment of the aeroplane through the air, it is necessary that the force OL should act as shown, along the lift axis.

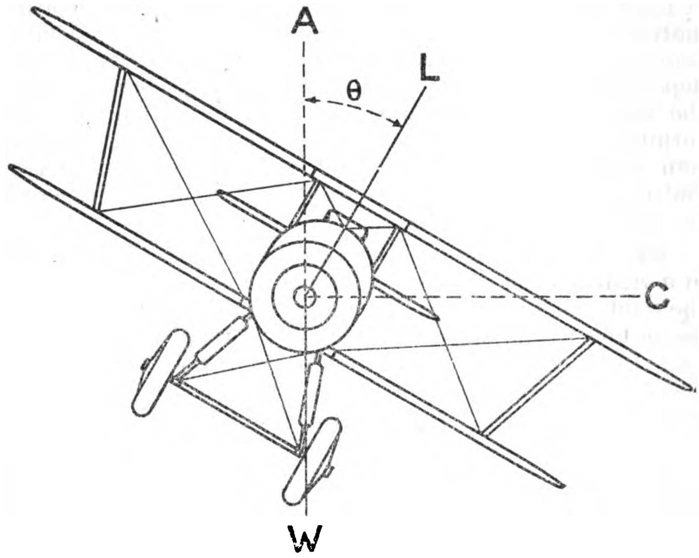


Fig. 35.

67. The centripetal force depends on the radius of the turn and on the air speed of the aeroplane, and is greater the smaller the radius. In a correct turn, therefore, the incidence and angle of bank must be such that OL is of the required magnitude and acts along the lift axis. The force OC acts at right angles to the drift axis, and if no other movement than the application of bank were made it would continue to act in the same direction while the aeroplane flew in a straight line. In order that it should always act towards one point the aeroplane must be rotated about a vertical axis. As this axis, when the aeroplane is banked, lies between the transverse axis and the normal axis of the aeroplane, this rotation is produced by using both the elevator and rudder together in proportion depending on the angle of bank (*see also* Chapter III.).

The motions of a turn.

68. It will be noted that the turning of an aeroplane is really composed of two motions, *viz.*, the motion of the centre of gravity of the aeroplane in a circle, and the rotation of the aeroplane about a vertical axis through the centre of gravity. If an attempt be made to turn by using the rudder only without banking, the centripetal force will be produced by the action of the air on the outer side (fin

surface) of the aeroplane. This implies inefficiency, and for various reasons is apt to be dangerous. If the aeroplane is overbanked the force OC will be greater than the centripetal force necessary, and the aeroplane will sideslip inwards until the excess is balanced by the air pressure on the inner side of the aeroplane.

69. In actual flying all these conditions are satisfied by trial and error, the pilot adjusting his controls until the aeroplane is turning in the desired circle and has no sidewise movement in the yawing plane, such sidewise movement being known, if outward as "skidding" and if inward as "side-slipping." The pilot can detect side-slipping by the side wind on his face and the direction of his apparent weight on the seat.

70. During the process of starting to turn, the aeroplane has to be accelerated in all three planes; it is, therefore, necessary to use all three controls together, in proportions varying with the nature of the turn. During a turn of, say, 45° bank, in a right-handed direction, the position of the controls is as follow :—

(i) *Rudder*—To the right, so as to produce right-handed rotation in the yawing plane.

(ii) *Elevators*—Slightly up to produce rotation in the looping plane. Both these planes being inclined to the horizon, the two moments combined cause a rotation in the horizontal plane.

(iii) *Ailerons*—At first in direction of bank; then, when the aeroplane is turning uniformly, in the opposite direction, the reason for this being as follows :—The outer wing is describing a larger circle than the inner one, and is therefore travelling at a higher speed. Since the incidence is uniform (neglecting small corrections for torque), this gives the outer wing a greater lift, thereby setting up a couple tending to overbank the aeroplane, which must be resisted by the use of the ailerons. Gyroscopic action must be resisted by the combined use of rudder and elevator, in a manner depending on the direction of the turn as explained in paras. 61–64.

Loading in turns.

71. It will readily be understood from para. 66 that in a steep bank the component (OA) of the lift (OL) in fig. 35, which supports the weight of the aeroplane, is a comparatively small part of the total reaction. For this reason the wings must be set to give a much greater lift than in straight flight, The ratio of the force OL to the weight of the aeroplane

(OW) (which is equal to OA) is called the "load **factor,**" and varies with the inclination of OL to the vertical (*i.e.*, with the angle of bank), if a turn is a correct one.

72. In a gentle turn, the load factor is comparatively small, but when the bank becomes steep it increases very rapidly, as shown in the curve in fig. 36.

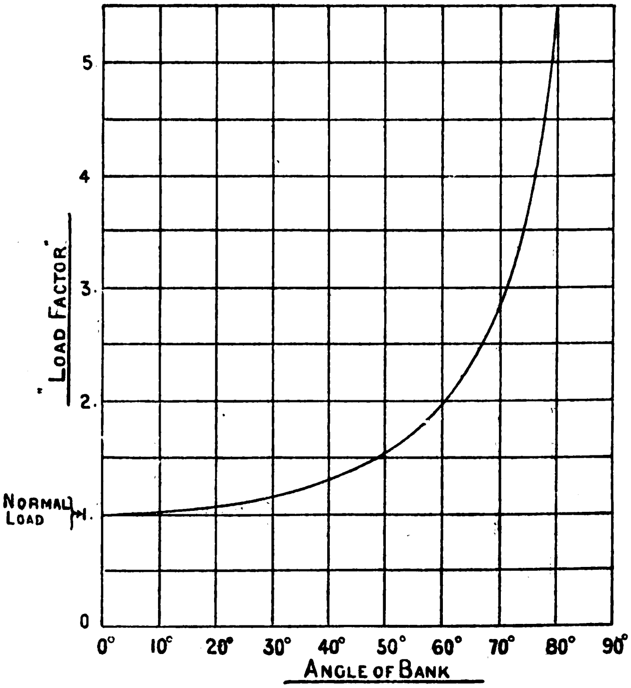


Fig. 36.

The load factor depends primarily on the angle θ (*see* fig. 35), and not on the angle of bank itself, and in an insufficiently banked turn is just as great as if the turn were a correct one, while the force OL is inclined to the lift axis of the aeroplane, and gives rise to stresses in abnormal directions.

73. The pilot's apparent weight increases in the ratio of the load factor, *i.e.*, if the latter is $2\frac{1}{2}$, the pilot's apparent weight is $2\frac{1}{2}$ times normal. This gives him an indication of the stresses in the aeroplane, and warns him when he is stressing it unduly. If it is desired to turn in a very small circle, the speed must be kept down in order to avoid overstressing. This is important in air fighting.

Stalling speeds whilst turning continuously in a horizontal plane.

74. It has been shown that the lift necessary in a turn, in order to have a vertical component of lift equal in magnitude to the weight of an aeroplane, is greater than the normal lift by the load factor. If an aeroplane be flown at the minimum level speed, which employs an angle of incidence very nearly equal to the critical angle, then a higher value of lift cannot be obtained without an increase in speed in the turn. If there is no increase in speed, the consequent increase in the angle of incidence about the critical angle will result in the aeroplane stalling on the turn. The greatest obtainable speed at an angle of incidence approaching the critical angle determines the maximum bank obtainable in a turn without loss of height.

75. The curve shown in fig. 37 is obtained by plotting stalling speeds against angles of bank employed where the level stalling speed is taken as 45 m.p.h. The ordinate values clearly show the increase in stalling speed as the angle of bank increases. Further, it should be noted that where small

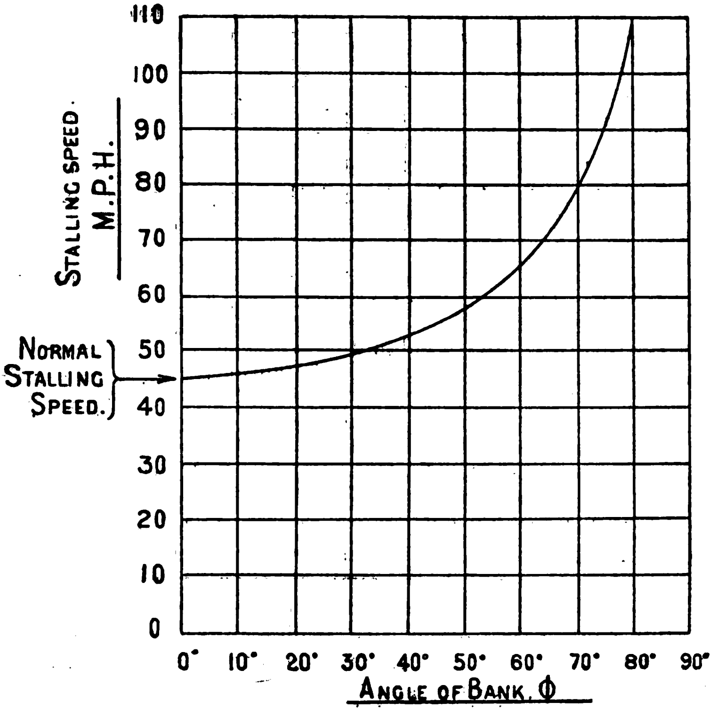


Fig. 37

angles of bank are used the increase in stalling speed is comparatively small.

Gliding turns.

76. The principles of gliding turns are the same as those of level turns, as described in paras. 65 *et seq.*, but with certain modifications, since the turning motion is combined with gliding. Since the loading is greater than in a straight glide, more lift must be provided and consequently a steeper angle of glide must be assumed. To provide the rotating moment and at the same time to keep the nose down to the angle necessary to maintain speed, more rudder and less elevator are used. Special care must be taken to avoid stalling by overloading, as a steep bank means a heavy loading, and demands more power, which necessitates a very steep gliding angle.

77. During a gliding turn there is little or no tendency for the aeroplane to overbank itself, and consequently bank need not be held off as in a level turn. This appears to be due to the fact that in a gliding turn the inner wing is describing a steeper spiral towards the earth than the outer wing, and thus meets the air at a greater angle of incidence. Thus as the air speed of different portions of the wing varies throughout the span by reason of the different radii of turning circle, so the incidence varies; and the extra incidence of the inner wing compensates for the extra speed of the outer wing which causes the self-banking tendency in a level turn. Gyroscopic action is absent, and the movement of controls is therefore the same in either direction of turn.

Power required to fly at minimum speed while turning continuously in a horizontal plane.

78. Since the minimum speed in a turn is higher than the minimum speed in normal flight, it follows that greater power must be expended by the engine in overcoming the greater drag at the higher speeds. The greater drag arises from the larger angles of incidence required to give the increased lift whilst the aeroplane is turned, as compared with the conditions in normal flight. For this reason an aeroplane can only maintain height whilst turning continuously by reason of the excess power available over that required for straight flight at minimum power. As the available engine power is limited, it will be readily understood why an aeroplane will stall on a steeply banked continuous turn, if flight in a horizontal plane be attempted. The limiting angle of bank will depend upon the excess power available over that required to obtain the speed in normal flight at minimum power.

Climbing turns.

79. In addition to providing the extra power necessary for turning, the engine has also to do work in lifting the aeroplane away from the ground. For this reason it is not possible either to use as steep a bank as on a level turn, or to climb as fast as if climbing straight. Although high-powered types of aircraft can climb quite fast with a fairly steep bank, on comparatively low-powered types such as training aeroplanes only quite a gentle climbing turn is possible. There is less tendency to overbank in a gliding than in a level turn, and a greater tendency in a climbing turn. This greater tendency is because the inner wing ascends at a steeper angle and has more incidence.

TAKING OFF.

Taking off from comparatively smooth and level ground under condition of no wind.

80. If the pilot opens out the engine, the thrust exerted by the airscrew accelerates the aeroplane in forward motion. The rudder is applied to counteract any tendency to yaw through the effect of torque or slip-stream. Whilst the wheels run over the ground, the aeroplane should move in a straight line, because if the line of direction is altered lateral stresses are imposed, particularly on the tyres and undercarriage.

81. With the acceleration in speed over the ground the elevators and rudder become increasingly effective, owing to the increase of air flow resulting from air speed and slip-stream speed. The tail should be raised until the longitudinal axis is almost parallel with the ground. The aeroplane is then in an attitude known as the "flying position" (*see* fig. 38). In this attitude the incidence of the wings, and

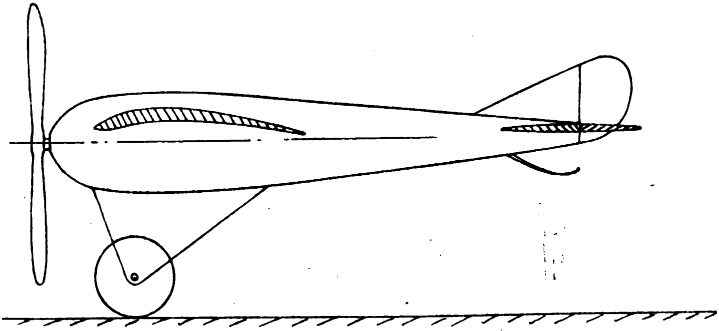


FIG. 38

consequently the wing resistance, is less than when the wheels and the skid are touching the ground.

82.—(i) The direction of the aeroplane's motion on level ground is horizontal, and the maximum wing incidence possible on the ground is the angle which the chord makes with the horizontal when the tail skid is touching the ground. There is thus a minimum speed at which the aeroplane will leave the ground. This speed may be termed "minimum *taking off* speed." It is not necessarily as low as the minimum speed that can be obtained in horizontal flight, since the maximum incidence obtained when the aeroplane is running with wheels and tail skid touching the ground is not necessarily as great as the maximum or stalling incidence that can be employed in flight. But in practice the speed of the aeroplane s accelerated over level ground with the tail up in "flying position" until the speed is well above the "minimum *taking off*" speed.

(ii) The attitude of the aeroplane should only be changed when the speed is well above stalling speed and the lift then obtained will raise the aeroplane off the ground. Before the aeroplane is allowed to climb it should be flown parallel to, and just clear of, the ground, until a sufficient speed has been reached to provide a large reserve of momentum. A further change of attitude should then be made so that the aeroplane will climb, until well clear of ground obstructions, at a speed somewhat greater than the best climbing speed, after which it should be held at best climbing speed. The angle which the longitudinal axis makes with the horizontal when climbing at the best climbing speed varies with each type of aeroplane, with the altitude, and with the density of the air.

83. In taking off from smooth, level ground with no wind, a certain time must elapse, during which the airscrew thrust accelerates the speed of the aeroplane up to "*taking off speed.*" If the aeroplane is not raised into flying position whilst thus accelerating, the average resistance will be greater and the time taken to attain the "*taking off speed*" will be longer.

Taking off from comparatively rough ground.

84. The aeroplane should be relieved as much as possible of shocks and stresses due to running over uneven ground. The best lift from the wings at speeds less than the "*taking off speed*" is obtained by accelerating with the skid on the ground. This lift increases from zero up to a value equal to the weight of the aeroplane, as it is accelerated from rest up to "*taking off speed.*" The curve in fig. 39 shows graphically the increase in lift with increase in speed.

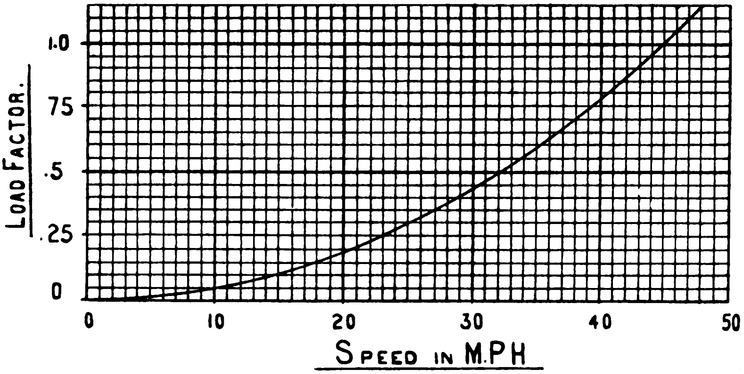


FIG. 39.

Taking off directly against the wind.

85. When there is no wind the ground speed is the same as the air speed. When a wind is blowing over the ground, the relative speed of the aeroplane in flight over the ground is known as the " ground speed." Thus if an aeroplane that leaves the ground at an air speed of 45 m.p.h. takes off directly against a 20 m.p.h. wind, the ground speed will be 45 − 20 = 25 m.p.h. The time taken to accelerate the speed of the aeroplane from rest to a ground speed of 25 m.p.h. will be less than the time taken to accelerate it to a ground speed of 45 m.p.h. under conditions of no wind. The length of run over the ground will be correspondingly shorter; moreover, the relief of the aeroplane's weight on the tyres resulting from the lift of the wings will have a higher value at corresponding ground speeds than under conditions of no wind.

Taking off down-wind.

86. If a 20 m.p.h. wind and an aeroplane with a " taking-off (air) speed " of 45 m.p.h. are again assumed, the aeroplane, in order to take off down wind, will have to be accelerated from rest up to a ground speed of 45+20=65 m.p.h. before a corresponding air speed of 45 m.p.h. is reached. The time taken for the run over the ground will be greater and the length of run correspondingly longer than under conditions of no wind. Moreover no relief of the aeroplane's weight on the tyres can be obtained from lift until after a ground speed of 20 m.p.h. is reached, and then only at very much higher ground speeds than under conditions of no wind. The resultant increased shocks between ground and tyres may impose serious stresses, especially on the undercarriage.

The greater time taken and the higher ground speed reached before the aeroplane takes off down wind together account for the greater distance the aeroplane must run over the ground.

LANDING.

Landing on level ground.

87. As the aeroplane glides towards the ground with the engine throttled down, the flight path is changed from the gliding angle to a path parallel to the ground. During this change, which is termed "flattening out," the forward speed is diminished until the aeroplane stalls. When this occurs, the position of the aeroplane relative to the ground should be such that the wheels and tail skid are just clear of the ground. Further, whilst "flattening out," the wing incidence gradually increases as the speed is diminished. This results not only in the weight of the aeroplane being sustained by lift, but also in the lift being such that the direction of flight is changed from the glide to a path parallel to the ground (*i.e.* when the aeroplane has no appreciable downward momentum). Under these conditions the aeroplane is stalled just above the ground, and will alight without undue shock.

Faulty landings.

88. If the aeroplane is not completely flattened out and stalled, shock due to impact will take place when the wheels touch the ground. Moreover, the reaction of impact in such a landing will be a force imposed in a line running nearly vertically through the wheel axles, and passing a point some distance ahead of the centre of gravity of the aeroplane (*see* fig. 40). Thus a couple is imposed which rapidly changes the attitude of the aeroplane and gives more wing incidence. If the speed at the instant this occurs is greater than that of stalling, the aeroplane will ascend (bounce) and unless it has sufficient remaining speed for a correction to be made to effect a second landing, it will probably stall at some height above the ground. In the event of a bad "bounce," it will probably be necessary for the engine to be opened up again.

89. When an aeroplane is thus stalled after "flattening out" too high above the ground, it will drop and hit the ground with a degree of shock, depending on the height from which it is stalled. Dropping on to the ground in this way is termed "pancaking."

Fast landings.

90. On a comparatively smooth surface a fast landing may be made by flying the aeroplane on to the ground so

that the wheels first touch lightly, and then come in contact with the ground as the speed is diminished; the tail is gradually brought down to position when the skid touches the ground. This type of fast landing may be the easier to execute on some types of aeroplane; but unless there is a strong wind to land against, or long run, overshooting is likely to result. Moreover, unless the surface is comparatively smooth serious bouncing may result from wheel shocks over uneven ground. In landing cross-wind, the aeroplane should be side-slipped to such an extent that the relative movement over the ground is parallel with the longitudinal axis.

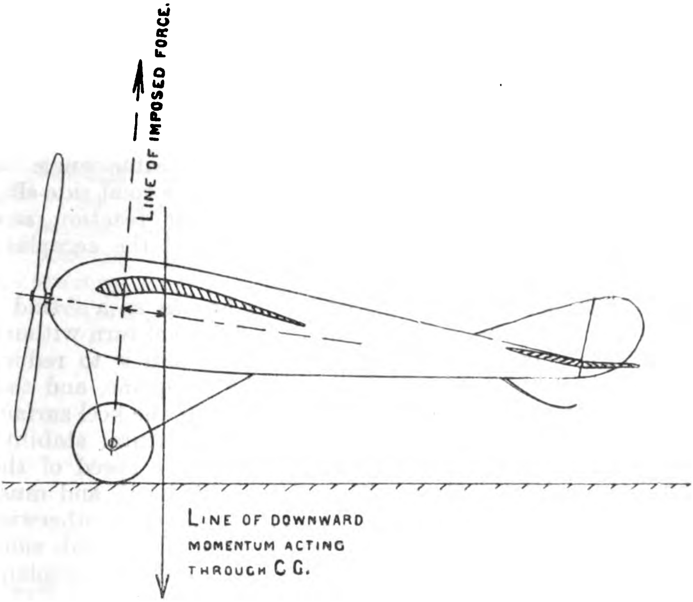


FIG. 40.

Side-slips.

91. In a turn an aeroplane is subjected to a force at right angles to the longitudinal axis (the centripetal force) and at the same time is continuously rotated about a vertical axis, in such way as to keep this force always acting through a fixed point. This point is the centre of the turning circle. It has been previously stated that unless the air reaction acts in the looping plane, the aeroplane will have sidewise movement in the yawing plane, which will result in inefficiency. This inefficiency may sometimes be useful in order either to lose height rapidly without gaining forward speed, or to lose forward speed rapidly.

92. In the former case (the normal sideslip), bank is applied, but the aeroplane is kept on a straight course by applying opposite rudder. The centre of pressure of the keel surface being behind the centre of gravity, a couple is introduced through the sidewise movement of the aeroplane tending to turn it in the yawing plane in the direction of the side-slip. This couple must be opposed by the rudder and owing to the higher loading the control column must be pulled back slightly to maintain a greater angle of incidence. It should be observed that in a normal side-slip, at a constant air speed, the resultant air reaction acts vertically through the centre of gravity and the aeroplane is in equilibrium.

93. The second kind of side-slip is known as a " skid " or " crab " side-slip, and is virtually a flat level turn without use of the engine. The object of the side-slip is to reduce the speed, by increasing the drag of the aeroplane, and this is done by applying rudder to one side so that the keel surface is presented to the wind. Owing to the natural stability of the aeroplane, and to the difference in the speed of the two wings, the aeroplane will tend to bank itself, and must be prevented from doing so by use of the ailerons; otherwise the side-slip will become an ordinary turn. In a crab side-slip, the lift loading is practically normal, and the aeroplane is not in equilibrium.

AEROBATICS.

Looping.

94. When an aeroplane is looped, a complete revolution about the lateral axis takes place. The looping plane is generally conceived as lying in the vertical plane with respect to the earth. A loop which lies at an angle to the vertical is termed a " side loop."

95. In order to execute a loop, sufficient forward speed must be gained for the accelerating force at the top of the loop to overcome the force of gravity. Under this condition there will be no tendency for any loose object in an aeroplane to fall out. The speed is greater at the commencement of the loop, and the change of direction in the looping plane should be gradual as possible, in order to relieve the aeroplane of undue overloading, but the change must be sufficiently rapid for the aeroplane to retain enough speed not to stall at the top. Insufficient initial speed or insufficient rate of change of direction will result in a stall upside down, or " hanging " on the top of the loop, the accelerating force in the curved path being less than the force of gravity. The radius of curvature of the loop at the top is less than the radius of curvature in other positions, since the forward

speed is then the minimum. The flight path of a loop is often conceived erroneously as being a circle. The performance of a loop with a circular flight path would be likely to impose greater stresses at the commencement of the loop than an aeroplane is usually designed to withstand if the balance of accelerating force and weight is to be attained at the top of the loop.

Loading during a loop.

96. Loading varies during a loop. In fig. 41 the load factors are shown thus: 2·9, against the approximate position where these loadings are attained. The stresses are imposed at the commencement of a loop where accelerating force and gravity are combined and act in the same direction.

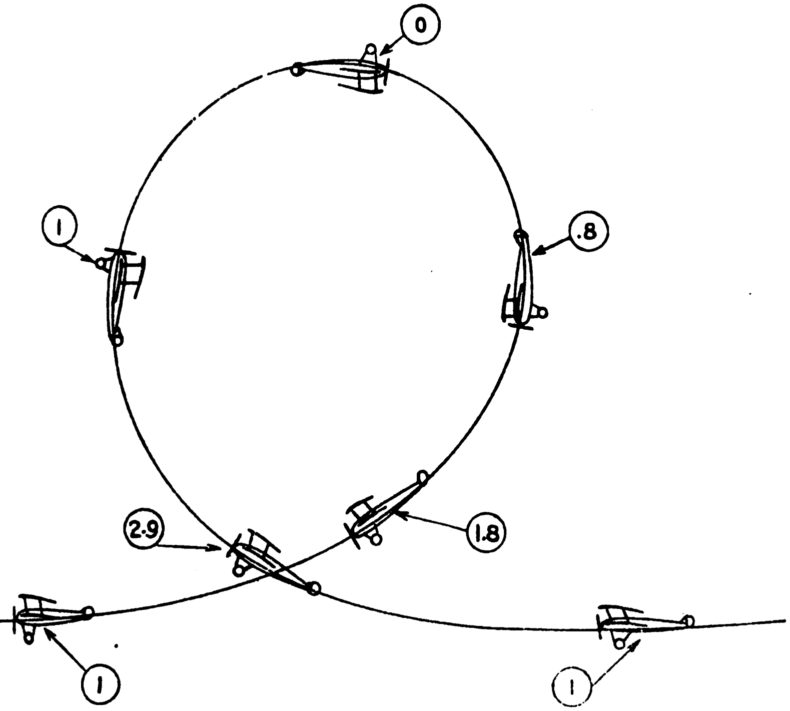


Fig. 41.

The spin.

97. When spinning, an aeroplane descends vertically under gravity, at the same time rotating about the spinning axis. The manner in which an aeroplane spins depends chiefly on the setting of the tail-plane and elevators and to some extent on the setting of the rudder. In general, an

aeroplane will attain a uniform spin with a given setting of the pilot's controls; but instances are known where the downward speed has never reached its maximum or critical speed.

98. Whilst the aeroplane is spinning, the longitudinal, lateral and normal axes are all inclined to the spinning axis, which is vertical. Thus, a spin is compounded of looping, yawing and rolling. The longitudinal axis may be inclined about 45° to the spinning axis, as in fig. 42, where the longitudinal axis lies in the plane of the paper.

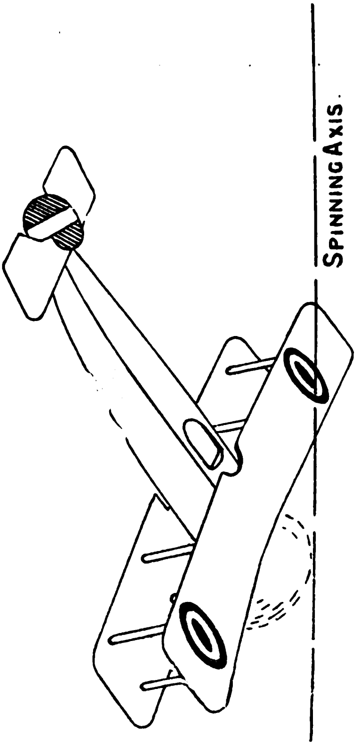


Fig. 42.

The lateral axis may be inclined about 60° to the spinning axis, as in fig. 43, where the lateral axis lies in the plane of the paper.

The position of a spinning axis relative to an aeroplane is shown in fig. 44, in which figure the spinning axis may be taken to pass perpendicularly through the plane of the paper at the point; the spinning axes vary in different conditions of spinning, and also in different aeroplanes.

The rate of spin and the downward speed also vary, so that an aeroplane may be spun slowly or quickly within the limits peculiar to that particular type. A Sopwith Snipe will spin about nine revolutions whilst descending 1,000 ft. with a path speed of about 80 m.p.h. An Avro may be spun about three revolutions whilst descending 1,000 ft. with a path

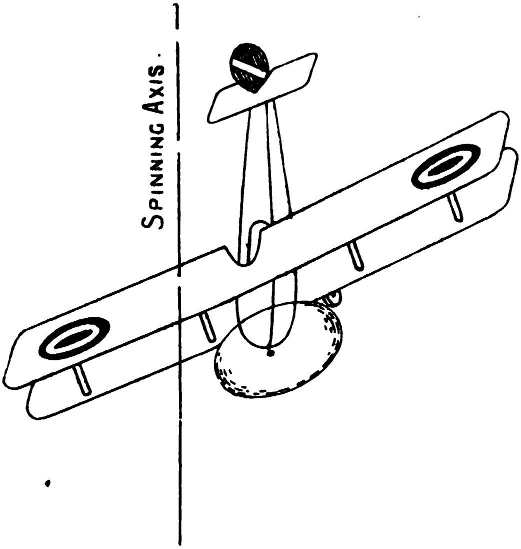


FIG. 43.

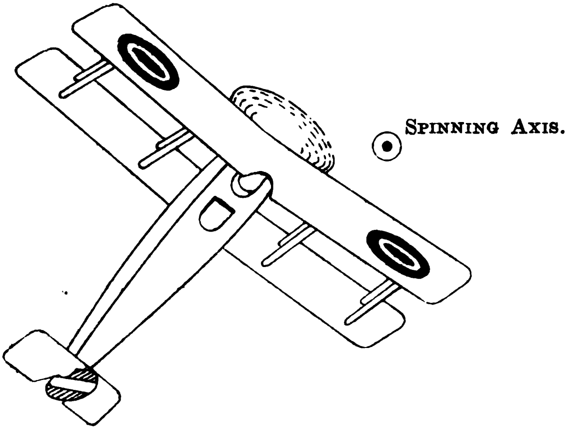


FIG. 44.

speed of about 70 m.p.h. Instances are recorded in which the downward speed has been as low as 40 m.p.h.

99. Spinning results from an initial stall and from slight yawing couple—*e.g.*, application of rudder when a condition of stalling is maintained. The weight of an aeroplane is borne chiefly by drag of the wings; the total lift from the wings is comparatively small, since the average angle of incidence may be as large as 30° .

100. When once an aeroplane has begun to spin, the difference of the incidence of the wings is considerable, since the inner wing is descending nearly vertically and so has an incidence almost equal to the angle between the longitudinal and the spinning axes, whereas the outer wing is descending in a spiral round the spinning axis. The actual angle of incidence of the outer wing tip may be somewhere near the stalling incidence, whereas that of the inner wing tip will be considerably greater. Thus the outer wing will have a certain amount of lift, which will have a moment about the spinning axis; whereas the inner will have very little lift since beyond the burble point the lift falls off with increase of incidence. The result is that a couple is set up which turns the aeroplane about the spinning axis. Moreover the drag of the outer wing is less than that of the inner and so causes the lateral axis to be at an angle less than a right angle to the spinning axis. The resulting couple acting in the yawing plane is balanced by the action of the air-flow on the keel surface.

101. The pilot has control over the lift and drag of the elevator and rudder surfaces, by which he may cause, maintain, or remove, the conditions of spinning.

The roll.

102. The motion of an aeroplane, and the forces operating when the total air reaction is not entirely in the looping plane are complicated, and manœuvres such as rolls can only be discussed here in outline.

103. In a roll an aeroplane executes a complete revolution in the rolling plane, but as a rule does not revolve exactly about its own longitudinal axis. There are two distinct forms of roll, and although the movements of the aeroplane are similar, the use of the controls and the forces acting are quite different.

104. In the "*slow roll*" the rotation is produced by the ailerons, and the movements of the aeroplane nearly approximate to a true rotation about the longitudinal axis The air reaction is nearly vertically upwards throughout the manœuvre, so that during half the roll the lift is actually

acting on the top of the planes—*i.e.*, in the negative direction of the lift axis.

105. The "*flick roll*" is carried out by combined use of the elevator and rudder. The motion and the forces acting are somewhat complicated, for, as in spinning, an aeroplane moves in all three planes at once. The actual motion is of a corkscrew nature, and while the aeroplane flies approximately along the rolling axis it is subjected to a varying acceleration directed towards this axis—*i.e.*, the axis of the corkscrew. The motion is produced by pulling back the control column and applying rudder to either side, according to the direction in which it is desired to roll. As the control column is back and the pilot is on the inside of the corkscrew the lift is always in the direction of the lift axis, but the loading is variable as in a loop. At certain periods the loading is high and accompanied by stresses in abnormal directions in the structure. For this reason a roll is liable to cause strains unless performed carefully on an aeroplane designed to withstand the stresses.

Inverted flight.

106. The aeroplane passes through an inverted position in the loop, but not strictly a state of inverted flight; for if the loop be correctly performed, the centrifugal acceleration at the top of the path is greater than the force of gravity, the pilot is still pressed against his seat, and the incidence of the wings is positive. In inverted flight the incidence is negative and the pilot is held in by the pull of shoulder straps. The wing section is cambered in the wrong direction for efficient performance, and the drag is therefore higher and the maximum lift coefficient lower than in uninverted flight. Stalling speed is higher.

107. When the controls are used in inverted flight the response of the aeroplane as viewed from the pilot's seat will be similar to that in normal flight. The result, however, of an apparent raising of the nose will be an increase instead of a decrease in speed; to carry out correct turns opposite bank will have to be applied and the pilot will be on the outside of the turn. The lateral stability will be different mainly because the dihedral angle of the wings is inverted, but this effect is less than might be supposed, because wings with no dihedral have a considerable "dihedral effect." The effect is not proportional to the dihedral angle, and so the dihedral effect is not simply inverted; if the dihedral be small, the dihedral effect will be reduced in inverted flight but may still act in the same direction.

108. An aeroplane which is longitudinally unstable in ordinary flight will usually be stable and in trim in inverted

flight, whilst an aeroplane which is stable in ordinary flight will remain stable in inverted flight but will be out of trim, and the control column must be held forward to retain the inverted attitude.

109. An aeroplane may be put through the usual aerial manœuvres when inverted, including the spin. In the inverted spin the wings are in the region of incidence which may be called "negatively stalled," while the cockpit is on the outside of the spin. The control is forward. Unless special arrangements are made the engine will run for only a very short time in an inverted position.

CHAPTER II.—AIRMANSHIP ON THE GROUND.

INSPECTION.

The responsibility of the pilot.

110. The useful employment of a pilot's skill in the air is contingent upon the airworthiness of his aeroplane and engine. This in turn depends not only on the treatment that the aeroplane and engine receive in the air, but also on the efficiency with which they are maintained on the ground A pilot must understand that his responsibility does not cease when he has brought his aircraft safely to earth, but that a thorough knowledge of the proper care of aeroplanes and engines constitutes one of the most important of his flying qualifications. Each aeroplane will normally be placed in charge of the officer or airman who flies it, and who is responsible to the flight commander that all required inspections are properly carried out. The inspection of an aeroplane and its engine is best performed under the supervision of the pilot who flies it for the following reasons :—

(i) He has a personal appreciation of the importance of discovering any fault before going into the air.

(ii) He knows whether any fault developed in his last flight.

(iii) He knows to what special strain his aeroplane has been subjected during flying or in landing, and therefore knows where to look for possible trouble.

111. Any fault or irregularity that may be disclosed during flight must be investigated in the pilot's presence, and no alteration or repair is to be carried out without his knowledge. He will always inspect and if possible personally test any work done in his absence; for example, after any

alteration of the wiring of switches the engine must be run up immediately and the switches tested. All engines have their peculiarities, and a pilot must learn his particular engine's good and bad points in order to obtain the best possible results. A pilot who shows an intelligent understanding of his aeroplane and engine and is capable, not only of pointing out its faults, but also of appreciating skilful and conscientious workmanship, will encourage his men to give of their best work.

Orders for inspection.

112. The serviceability of aircraft depends on their being kept in proper working order day by day, and this condition can only be maintained if both aeroplane and engine are subjected to frequent and systematic inspection. The detailed requirements of inspection vary with the type of aeroplane and engine in use, and depend on other considerations, such as climate and weather. Officers commanding units are responsible for the publication of adequate orders for the inspection and maintenance of aeroplanes and engines, and these orders must be scrupulously followed in order that no details may escape notice. Haphazard methods of inspection are to be avoided.

113. The principles on which the inspection and maintenance of aeroplanes are to be carried out are contained in Air Ministry Weekly Order 850 of 1924 (amended by Air Ministry Weekly Order 886 of 1924 and 26, 244, 611 and 792 of 1925). Suggested details of inspection are given in the R.A.F. Field Service Pocket Book. Flight commanders are to make percentage checks at least once weekly to ensure that the routine inspection is being properly carried out, and similar percentage checks are to be made daily by pilots in charge of aeroplanes to ensure that fitters and riggers are performing their duties satisfactorily. In addition to the complete inspection of aeroplanes to be undertaken periodically as laid down in the orders for the unit, advantage should be taken of occasions when the weather is unsuitable for flying, to make extended percentage inspections. Pilots should realise that if these percentage checks are carried out frequently and thoroughly, a high standard of maintenance will be enforced, and the necessity for close inspection by the pilot immediately prior to flight will be greatly reduced.

114. The full details of maintenance and inspection, as outlined in the appendix to the above-mentioned Air Ministry Weekly Order, and the division of responsibility for particular duties will be contained in the unit orders. There are, however, certain points of maintenance in which the pilot of an aeroplane has particular interest. Some of these points

are common to all aeroplanes, others are peculiar to a type, while others may be peculiar to an individual aeroplane. (*See* Appendix III.)

Special points for percentage checks.

115. (i) *Engine.*—The following should be examined:—locking nuts, filters, bearer bolts, exhaust pipes, valve tappet clearances, valve springs. Carburettors are to be examined for corrosion. In rotary and radial engines the rocker arm fulcrum pins, the rocker arms and other portions of the valve gear must be properly lubricated. Tappet rod locknuts must be secure.

(ii) *Ignition.*—Magnetos must be clean and dry. Carbon brushes, contact breakers, plugs and plug terminal fittings, and all H.T. leads must be carefully examined. Special care is necessary in rotary engines that ignition wires and H.T. terminals are secure at the distributor, and that sparking plugs and magneto contacts fit tightly.

(iii) *Switch wiring.*—Switch wiring and earth leads must be closely inspected. The importance of this examination cannot be over-emphasised, and every precaution must be taken to prevent defects in the wiring which may cause an engine to start when the magneto switches are not on contact. Attention will be paid to the tightness of screws in the switches, and care taken not to strip the thread of these screws when they are being tightened up.

(iv) *Petrol.*—Filler caps must fit tightly, and if a gravity tank is used the vent must be clear. The quantity of petrol in the tank must be checked frequently by the pilot. Auxiliary hand pumps, mechanical pumps, pipes, pipe unions, cocks and gauges must be inspected and release valves tested. The gland nuts on mechanical pumps must make a petrol-tight joint without causing excessive friction on the pump spindle on rotation. Propellor driven pumps must be rotated by hand to ensure that they work freely. It should be observed that lubricating oil has been used where necessary.

(v) *Oil.*—The oil tank, pipes, pipe joints and cooling devices should be examined. The quantity and quality of the oil must be inspected frequently.

(vi) *Radiator.*—The radiator must be full, with caps and drain taps secure, and the shutter control lever correctly adjusted. Leaks must be detected. The radiator must be insulated from shock by rubber blocks, which must be examined periodically.

(vii) *Cowling.*—The cowling must fit accurately, and all side shields and fasteners on doors must be securely fastened. Cowlings should be examined for cracks due to vibration.

(viii) *Undercarriage.*—Split pins in the undercarriage axle and all fittings should be examined. Shock-absorbers are to be examined for perishing of the rubber. Wheel axles must be thoroughly greased.

(ix) *Airscrews.*—Airscrews must be kept dry and clean, and the blades closely examined for warping or splitting of the laminations. Play on the engine shaft, or slackness of bolts in the boss must be detected. The welded seams and sockets of metal airscrews should be specially inspected.

(x) *Instruments.*—All instruments must be in working order. The air-speed indicator pipe-line should be examined for leaks and the pitot head for possible damage. The compass must be swung periodically, as laid down in unit orders.

(xi) *Controls.*—All control cables, wires and fittings must be kept coated with oil or grease to prevent rust. Care should be taken to prevent dust and grit from accumulating on the oil or grease, as not only may the lubrication be thereby affected, but friction and wear will be caused, and defects may become hidden from notice; external wires and control cables should therefore be oiled and greased daily, especially at fair leads and pulleys. Piano-wire loops and cable splices should be examined. Cables should be passed to and fro between forefinger and thumb to brush up any parted wires; even if there is only one strand broken the cable should be changed. The hinges of all controlling surfaces should be examined to ensure that they are pinned and properly greased.

(xii) *External bracing wires.*—Close inspection should be made of bracing wires which may have started to draw owing to shock when the aeroplane has been taking off or landing; the cause of slackness in a bracing wire must be carefully investigated, as a more serious fault may be disclosed. All streamline wires should be locked and lug pins secured. Streamline wires should be turned correctly in the direction of flight. Turnbuckles must be locked with wire, and should be examined for rust.

(xiii) *Internal bracing wires.*—Inspection is to be made for slack internal bracing wires, which will rattle if the planes be struck with the clenched fist. The amount of tortional whip in the tail should be tested, and the rudder examined for warp.

(xiv) *Fabric.*—Fabric should be examined for deterioration. Fabric holes should be repaired at once. (*See* para. 398.)

(xv) *Wood parts.*—There should be no signs of defect. Struts must be straight, as departure from truth is liable to be accentuated by end pressure to an extent sufficient to cause collapse or fracture.

(xvi) *Metal parts.*—There must be no signs of rust or defects on any metal part. All bolts must be securely locked, but spring lock washers or locknuts are not to be used. The accepted method is by castellated nuts and split pins, but where a nut need not be removed afterwards, the end of the bolt may be riveted over. Strut sockets and metal fittings must be removed if they have bent out of their original shape.

(xvii) *Tools, etc.*—After any work has been carried out, inspection should be made to ensure that no loose tools or parts have been left in any portion of the aeroplane.

Pilot's inspection prior to flight.

116.—(i) *Controls.*—All controls must move freely and smoothly when tested from the pilot's seat. Tail-plane adjustment gear should move satisfactorily, and the maximum, medium and minimum positions should be observed.

(ii) *Engine controls.*—These should operate firmly but without stiffness. The altitude control must be secure, and the radiator shutter control in order. The tumblers of ignition switches should move with a definite tension, but with unobstructed action.

(iii) *Petrol, oil, water.*—The pilot will ascertain from the fitter in charge of the aeroplane that the required amounts of petrol, oil and water have been provided. The pilot will ensure that oil and fuel pressures are maintained.

(iv) *Pressure systems.*—Pressure systems must be tested and the valves adjusted to release at the correct poundage.

(v) *Instruments, etc.*—The aneroid and watch must be checked and adjusted. Adjustable windscreens must be firmly secured.

(vi) *Safety belt.*—The safety belt should fit closely but comfortably across the chest, and the clip should fasten and unfasten easily. Belts in vacant seats will be so secured that they can in no way foul the controls.

(vii) *Ballast.*—Where ballast is required it must be of an approved form (*i.e.*, bags filled with earth or sand, or sheet lead in strong canvas covers) and of correct weight. The pilot must see that the ballast is properly secured and that there is no possibility of its fouling the controls.

(viii) *Loose articles.*—The pilot is responsible that loose articles are properly placed and secured and that there are no loose cushions in seats not occupied.

(ix) *Lubrication.*—If the engine has been standing for a considerable period, the pilot must ascertain from the fitter that the oil has been evenly distributed throughout, and that all tappets, rockers, valve stems and external bearing surfaces have been lubricated.

(x) *Fire precautions.*—Fire-extinguishing appliances of approved pattern must be carried in the aeroplane. Matches, other than of the approved "Safety" type, are not to be carried by the occupants of any aircraft.

(xi) *Shock absorbers.*—Tyres must be free from oil, and inflated to the correct pressure. Shock-absorbers are to be examined for undue slackness.

Inspection after flight.

117. On landing, a pilot must at once acquaint his mechanics with the performance and condition of the aeroplane and engine. Pressure must be released, and petrol taps and ignition switches turned off.

118. A brief examination should be made in accordance with the routine laid down in unit orders, special care being exercised to detect any of the following signs of engine trouble :—

(i) Overheating.
(ii) Oil, petrol or water leakage.
(iii) Heated airscrew boss :—airscrew loose or out of truth or damaged.
(iv) Exhaust valve springs or rockers broken, burnt or distorted.

The undercarriage and suspension, and the tail-skid should also be examined.

THE CARE OF AEROPLANES.

The importance of cleanliness.

119. The importance of keeping aeroplanes clean cannot be over-emphasised. Dirt and oil cause fabric to deteriorate rapidly, and must be removed with soap and warm water as soon as an aeroplane returns to the sheds. Petrol must not be used for this purpose. Mud thrown on to the fabric by the wheels of the undercarriage should not be allowed to dry, but must be removed as soon as possible. If circumstances do not allow of this and the mud dries, it must be removed with warm water and not scraped off, as otherwise the fabric may be damaged.

120. It is equally important to keep all woodwork scrupulously clean, and the cockpit and fuselage must be free from grease and mud. Mechanics must not be permitted to work in the cockpit when their overalls are in a very dirty condition; nor to stand on unprotected seat cushions when

their boots are greasy or muddy. Mechanics should be encouraged to take a pride, not only in the running condition, but also in the appearance of the aeroplanes to which they are allotted. Suitable brass and other metal parts must be brightly polished; the cockpit and its instruments must be kept in a condition comparable with the dashboard and driving seat of a well-cared-for motor car and fabric must be re-doped as soon as frequent washings begin to affect it.

121. It is easier to keep aeroplanes clean if they are housed under clean conditions, and hangars should therefore be inspected daily and cleaned out at least once a week, when all unessential equipment should be removed. It is preferable to prevent dirt appearing than to remove it, and unnecessary work can be avoided if ordinary care is taken. For example, aeroplanes running up and taxying near sheds must be manœuvred so that the minimum amount of dust is blown towards the hangars; and immediately an aeroplane enters the hangar, a tray must be put under the engine to prevent oil dripping on to the floor.

Housing the aeroplane.

122. It is advisable to leave as much space as possible between aeroplanes in hangars, in order to facilitate inspection and cleaning. When housed, they must never be allowed to rest so that strain falls on the flexible suspension of the wheels, but must be supported by small trestles or chocks placed under the undercarriage struts so that the wheels and shock-absorbers are relieved of all weight. The tail must be supported by a trestle under the fuselage directly below the inter-longeron struts. (*See* fig. 45.)

123. Aeroplanes must not be exposed to extremes of heat and cold, nor to prolonged dampness. However well-seasoned the wood may be, it will deteriorate if it is allowed to absorb moisture. Sheds should therefore be kept dry, and as far as possible at an even temperature. Struts and spars are likely to become damaged if left lying on the floor of a hangar; moreover, wood easily becomes distorted, and must be stood as nearly vertical as possible, and shielded from the sun. This applies particularly to the interplane struts. Airscrews out of their cases should not on any account be stood or rested on their blades. No part of the aeroplane that is covered with fabric should be placed on a concrete floor, as any slight movement of the part will cause damage.

124.—(i) When repairs or adjustments are being carried out, tools, nuts, bolts, etc. must not be placed on any part of the aeroplane, but must always be kept in a tool box when they are not actually in use. If they are carelessly left

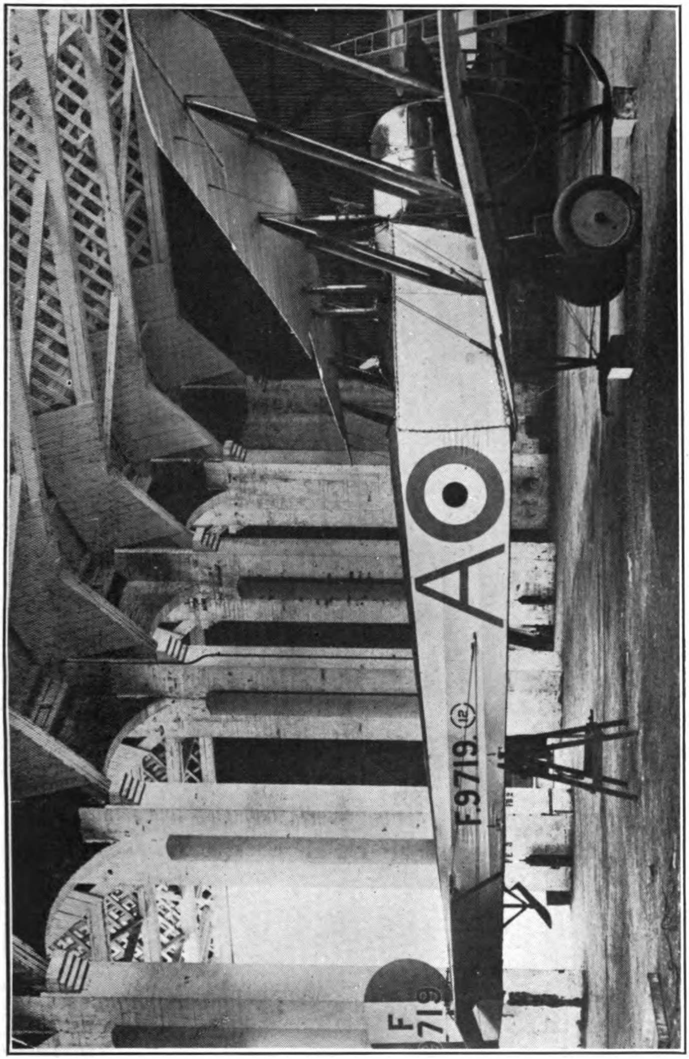


FIG. 45.

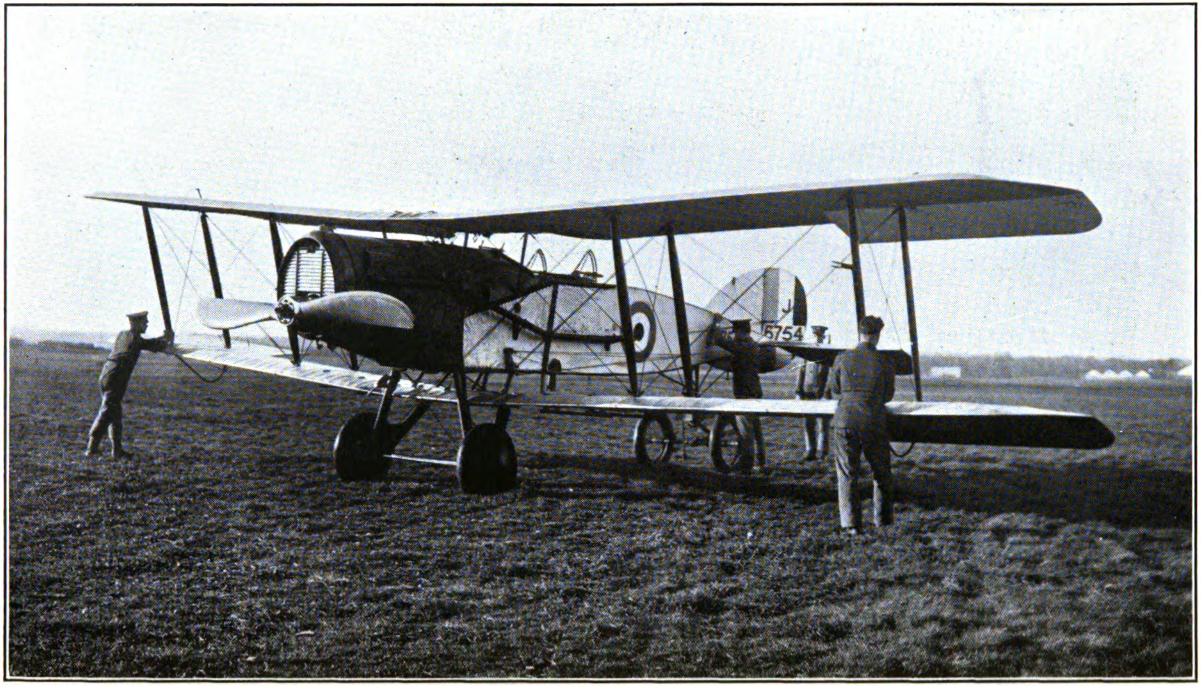


FIG. 46.

on the aeroplane it is possible for them to slip back and jamb the controls.

(ii) In order to safeguard aircraft and buildings from fire—

(*a*) Buildings containing aircraft must be inspected by an officer within two hours of the cessation of work.

(*b*) Blow-lamps, naked lights, or smoking will not be permitted in the vicinity of aeroplanes or hangars.

(*c*) The accumulation of empty petrol tins, waste impregnated with petrol, dope, oil or any other combustible rubbish, must not be permitted.

(*d*) Special precautions are to be taken during the filling and emptying of petrol tanks in aircraft.

(*e*) Petrol will not be used for cleaning hands or clothing and must not be stored in the hangar.

(*f*) Fire-fighting appliances must be adequate, and all personnel must be instructed in their correct use.

(*g*) After a forced landing or accident of any kind no smoking will be permitted in the vicinity of the aeroplane.

(*h*) Fire extinguishers will be carried on all aircraft. (*See* The King's Regulations and Air Council Instructions, Chap. XII, para. 653.)

Moving aeroplanes in and out of hangars.

125. When an aeroplane is being moved, one person. preferably the pilot, will supervise and direct the operation, If the assistance of inexperienced persons is necessary, the utmost care must be taken to prevent them from handling the aeroplane in such a manner as to cause damage; the pilot himself will station each person, explain the nature of the help required, and demonstrate the correct method of carrying out his instructions.

126. Aeroplanes must be lifted by pressure under supported points, such as the vertical fuselage struts or the interplane struts. They must be moved by pressure on the base of the interplane struts, and not on the leading or trailing edges of the planes. The tail-skid trolley must always be used for movement in and out of a hangar, and care must be taken to prevent wing tips from colliding with hangar doors. Under normal conditions single-seater and two-seater aeroplanes are best moved by stationing one man at each wing tip to guide and steady the wings, and one at the tail to work the tail-skid trolley (*See* fig. 46). If the aeroplane must be moved during windy weather, the control lever and rudder bar must be lashed.

Moving aeroplanes over bad ground.

127. Before an aeroplane is wheeled or taxied over bad ground, the pilot or some responsible person must first inspect the area ahead, so that holes or obstacles may be avoided. If a tail-skid trolley is not being used, the tail must be lifted by two or more men; this is made easier if one man hangs as a counter weight on the propeller boss, but care must be taken not to tip the aeroplane up on to the nose. (*See* fig. 47.)

128. An aeroplane on very heavy ground may require a track formed of planks laid on the ground. To assist in moving out of mud on to a track, part of the weight may be taken off the wheels by mechanics pressing under the lower planes with their shoulders. The pressure must be applied under the main spars and directly under the interplane struts. (*See* fig. 48.)

Picketing aeroplanes in the open.

129. When it is necessary to picket down in the open, the aeroplane must be placed head to wind and the control column lashed in neutral position. An aeroplane must not be picketed with wings folded, but must be completely rigged as for flying.

130. The aeroplane must be secured primarily to counteract the tendency of the wind to lift and drive it backwards, but also to prevent any forward movement, rocking, or "slewing" to the side. The tail must be raised to a height of five or six feet, and placed on a stout trestle, a hedge bank, a lorry, or some similarly firm support. If it is necessary to use a comparatively light object, it must be heavily weighted and lashed firmly to the ground. A lorry or trailer will usually be found most convenient for very heavy aeroplanes, which can then be easily turned into wind should the wind change. The weight of the fuselage must be taken on the tail-skid, so that if the aeroplane rocks a little laterally it will pivot on a central point and not twist on the longerons. The tail-skid must be lashed so that it cannot move on its support, and the fuselage secured so that it cannot move unduly if the wind should veer so as to strike it on the side. These lashings must be as taut as the tension in the tail skid will permit. Chocks must be placed behind the wheels.

131. Wire lashings are better than rope as they are not subject to shrinkage. Picket ropes securing the airscrew boss and wing tips should be hung with heavy weights, such as cans of petrol. These produce a tension which eliminates undue shock to the aeroplane and prevents the pickets from being jerked out. Corkscrew pickets cannot be trusted under all conditions; they should be placed in pairs, tied together,

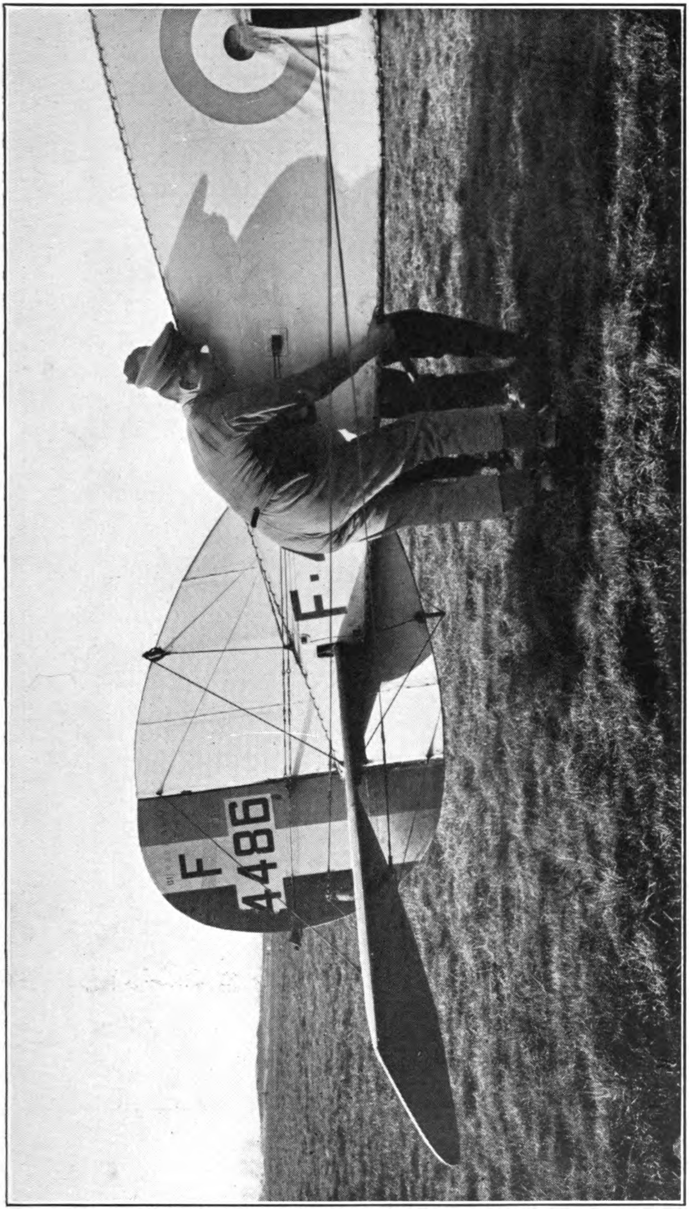


FIG. 47.

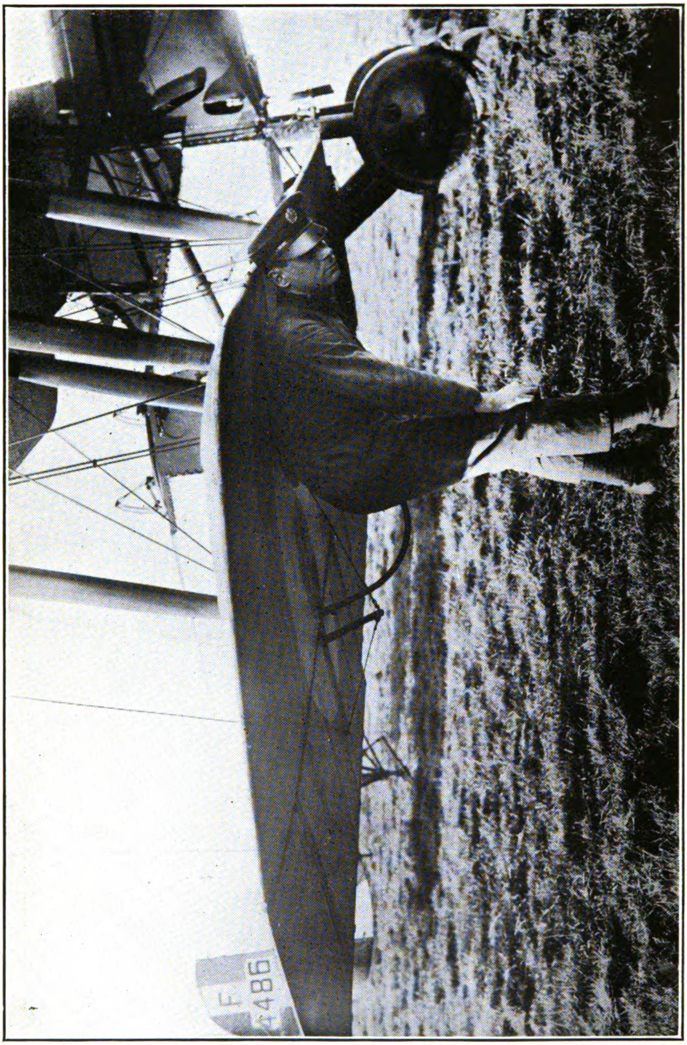


FIG. 48.

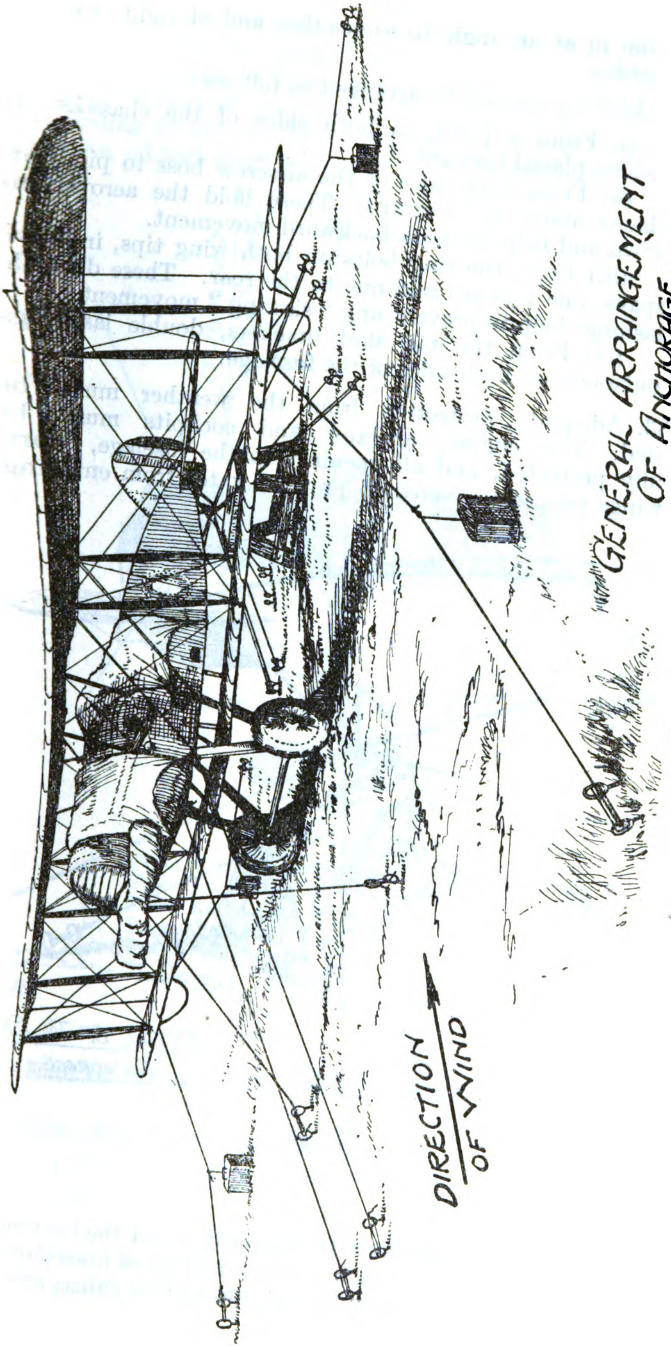


FIG. 49.

and driven in at an angle to each other and at right angles to the lashing.

132. Lashings should be arranged as follows :—

(i) From a point on both sides of the chassis to pickets placed forward.

(ii) From both sides of the airscrew boss to pickets placed about 45° forward. These hold the aeroplane down and help to check backward movement.

(iii) From the ring bolts on both wing tips, in two spans, one forward and one to the rear. These double lashings help to prevent any "slewing" movement.

(iv) From the tail skid brackets, double lashings outwards on both sides of the fuselage.

133. Adequate protection from the weather must be provided. The engine, airscrew and cockpits must be carefully protected, and all openings in the fuselage, fabric and wings properly covered to prevent water from entering.

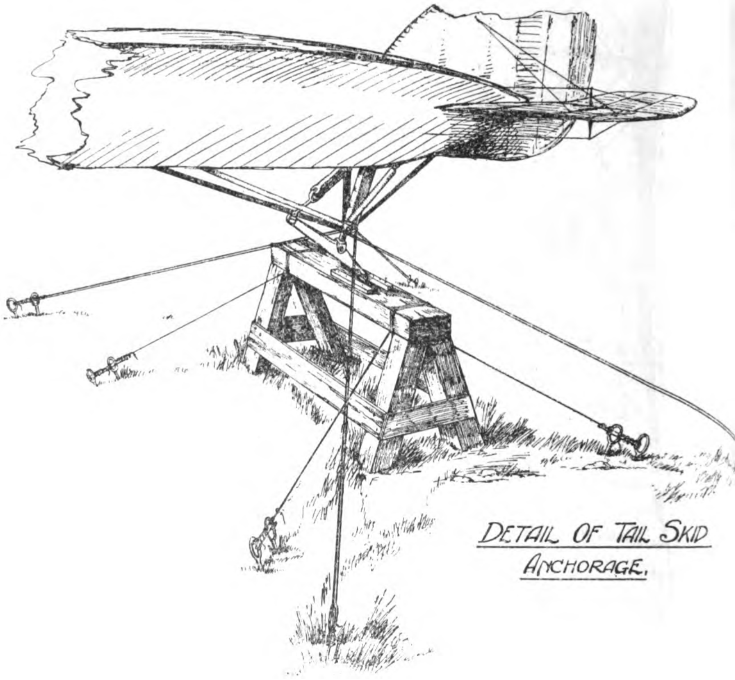

DETAIL OF TAIL SKID ANCHORAGE.

FIG. 50.

Cloths or cotton waste must be wrapped round the lower end of struts and wires abutting on the main spars of lower planes, so as to prevent water from running down and gaining access to the interior of the planes. In damp or cold weather the magnetos must be packed round with cotton waste. In tropical climates special measures will be necessary to protect airscrews and fabric from the heat of the sun. According to circumstances imposed by season, weather, or climate, oil and water may need to be drained off.

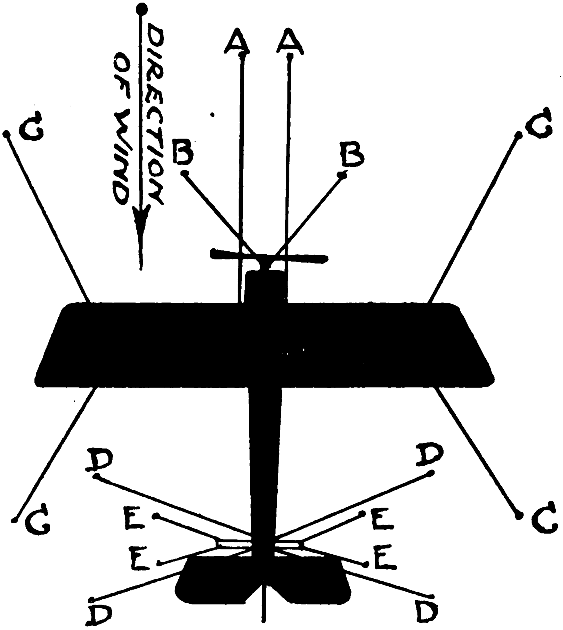


Fig. 51.

A. From a point on both sides of chassis.
B. From both sides of Airscrew Boss.
C. From Ring Bolts on both Wing Tips.
D. From Tail Skid Brackets.
E. Trestle Anchorage.

ENGINE STARTERS AND AIRSCREW SWINGING.

Methods of starting aero-engines.

134. The principal methods of starting aeroplane engines are as follow :—

(i) Swinging by hand. This is dealt with in paras. 137–143.

(ii) Starting magneto and priming device.

(iii) **Swinging in combination with a starting magneto.** The starter handle is turned as the airscrew is being swung. *See* para. 149 (iv).

(iv) Compressed air or gas starter. *See* para. 135.

(v) Hand cranking gear.

(vi) Power-driven airscrew swinger, such as the Hucks Starter. *See* para. 146.

Compressed gas starters.

135. A compressed petrol-air mixture from a power-driven compressor carried in the aircraft or mounted on a trolley with provision for coupling, is introduced into the cylinders of the aeroplane engine by means of a distributor. This distribution is so timed that the mixture enters each cylinder through a non-return valve at the commencement of what is normally the firing stroke. The engine is turned by this compressed mixture, and a portion of it is used to prime the induction system. After two or three revolutions, a H.T. current is switched on to the starting terminal of one of the aeroplane engine magnetos, when a start and subsequent normal "pick up" on the magnetos and carburettors is obtained.

136. The gas starter is operated in the following manner. The control valve on the starter cylinder head is turned to the proper position for delivery to the aeroplane engine, and the control cock in the pilot's cockpit to the position for blowing off. The H.T. switch must be in the "off" position. The compressor is started and opened to full throttle; the pilot's blow-off cock is closed; and the pilot's engine-throttle is adjusted to the normal starting position. After a few revolutions of the aeroplane engine the H.T. current is switched on by the pilot. When the engine starts, the H.T. current is switched off, the blow-off cock opened and the compressor stopped.

Precautions to be observed when swinging by hand.

137. Although mechanical starters should be used as much as possible for routine work, all personnel are to be taught the correct methods of airscrew swinging, and sufficient tests and practices are to be held to keep the standard of airscrew swinging up to the highest degree of efficiency. (*See* Appendix I.) Although the pilot of an aeroplane will normally be seated in the pilot's seat, and be engaged in manipulating the engine controls, he must be able to swing an airscrew himself so that he may be qualified to instruct others, and so that in the event of a forced landing he may be able to restart his own engine.

138. Very serious accidents may follow if an airscrew is swung, or even slightly moved, by careless or untrained personnel. The pilot must realise that if an accident does occur while starting-up he will be held responsible. He must therefore ensure by frequent personal inspections, that the switches and switch wiring are in order, and will on all occasions follow the correct routine for starting aircraft engines. The airscrew must always be handled with the greatest caution, whether the switch is "on" or "off," and the pilot must keep his hand clear of the switch except when actually making contact or switching off. The airscrew must not be touched, except for the swing for starting, until both mechanic and pilot are certain that the controlling switch is "off": and to ensure this condition is fulfilled the following procedure must invariably be followed as a matter of discipline and without regard to the number of times it may be necessary to swing the airscrew of a refractory engine.

139. *The airman about to touch the airscrew will always call "switch-off." The pilot, after making certain that the switch tumbler is down in the "off" position will repeat "switch-off."*

140. When an engine is hot from recent running, there is a possibility that turning the engine may cause it to start, although the switch is "off." Engines that are hot are therefore to be regarded as on contact, and handled with corresponding care. Airscrews must be swung a few times as for starting, with ignition switched off and throttle closed, to make sure they are safe before "sucking in" is commenced.

141. It is usually necessary for the airscrew of high-compression engines to be handled by two men in order to bring it over compression point. This procedure entails special care on the part of the pilot and of the men who are swinging it and also very thorough inspection of the switch wiring system (*see* para. 115 (iii)). In no circumstances must an airman force the airscrew over compression by pressure with his shoulder.

142. The pilot must not commence to start his engine until he is assured that the chocks are in position. The aeroplane must be placed so that the airman swinging the airscrew is enabled to obtain a firm foothold with both feet, and if necessary sand must be laid, or the aeroplane moved until it is over suitable ground; care must be taken that the ground is free from stones which may be drawn up by the airscrew and cause damage. It may be desirable to move the aeroplane several times in wet weather, as repeated attempts to start an engine will soon cause the ground to become slippery. The [airman swinging the airscrew must

always remove his headgear, as this is liable to fall off at a critical moment; he must take the greatest care to keep clear of wires and skids, and of the path of the airscrew. The airscrew must be grasped with both hands by the top side about two-thirds of the way along the blade from the boss. It must be turned round several times until sufficient petrol gas has been sucked in and must then be brought to rest in such a position as to be on compression and at the same time afford a good hold at the full extent of the arms. When swinging the airscrew for starting, the airman must pull it firmly and quickly over compression, following through with his arms and moving clear away in practically one movement. During no part of the operation must he allow his weight to hang on the propeller. (*See* figs. 52 to 54.)

143. On slippery ground, or where an engine is difficult to pull over compression, the airscrew turning may be facilitated by the assistance of one or two more airmen. The airscrew is swung up by the first man with one hand, his disengaged hand being clasped by the second airman, whose other hand in turn is held by the third man. On the starting swing being given, the first airman is pulled by the others clear of the path of the propeller, and is thus enabled to exert his full strength and follow through with the swing (*see* fig. 55).

Position of mechanics when about to start.

144. The number, distribution and duties of the men required to start up an aeroplane will depend upon its type and upon the number of engines. The requirements for a single-engined aeroplane of normal size are shown in fig. 56.

145. As soon as an aeroplane has been moved into position ready for starting up, chocks must be placed under the wheels, so that the ends to which the cords are attached are pointing inwards, the cord being carried outwards round the chock and back to the wing tip. Mechanics must then take up positions at each wing tip, in front of the leading edge and facing the pilot. Each mechanic will hold the chock-cord with one hand, and with the other will press against the front outer inter-plane struts. A third mechanic must stand at the tail, looking towards the pilot and holding down the longerons immediately over the inter-longeron struts. The N.C.O. or airman in charge must take up a position in front and to one side of the outer wing-tips, so as to have an unrestricted view of the aerodrome. When the pilot is ready to start, the procedure for starting as given in para. 149 must be followed.

146. When a Hucks starter is used, an airman will mount the front platform of the Hucks starter and attach the starting shaft to the fitting on the airscrew. This airman must give

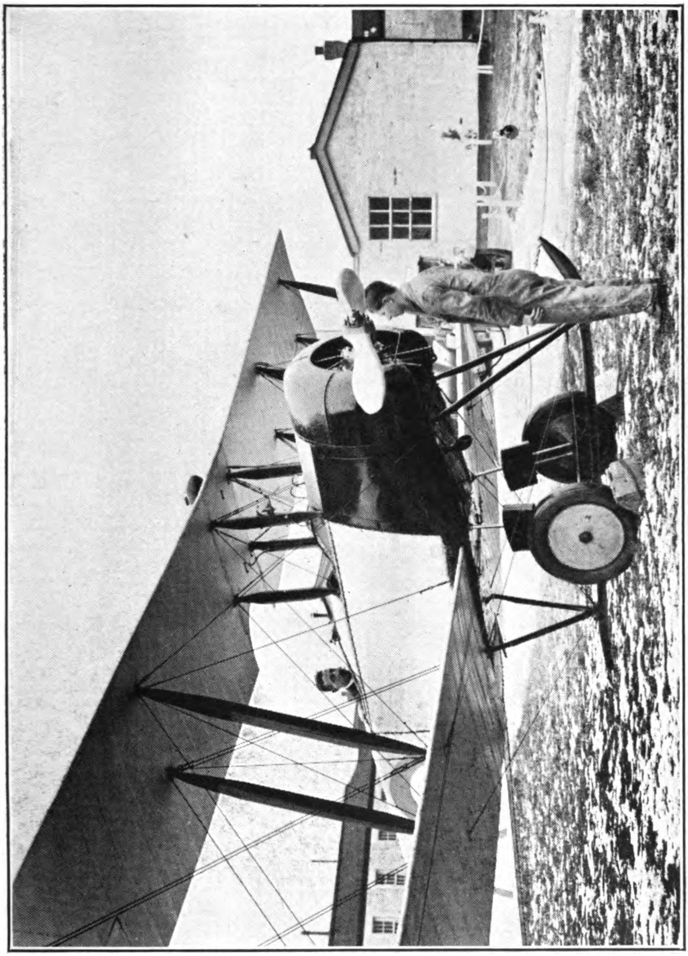


Fig. 52.

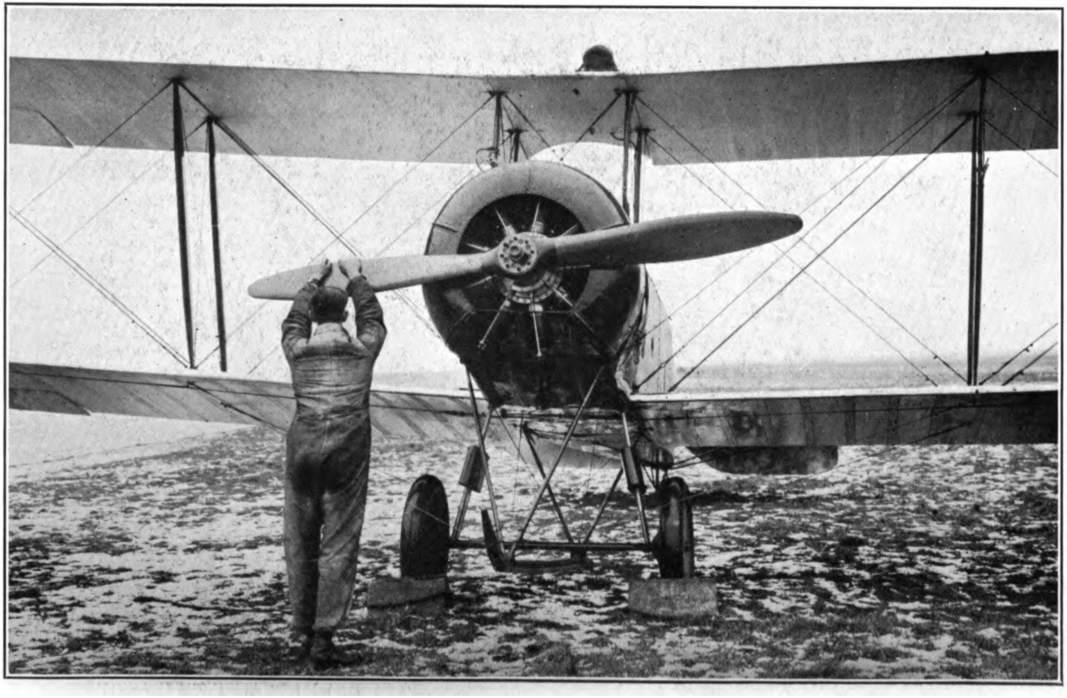


Fig. 53.

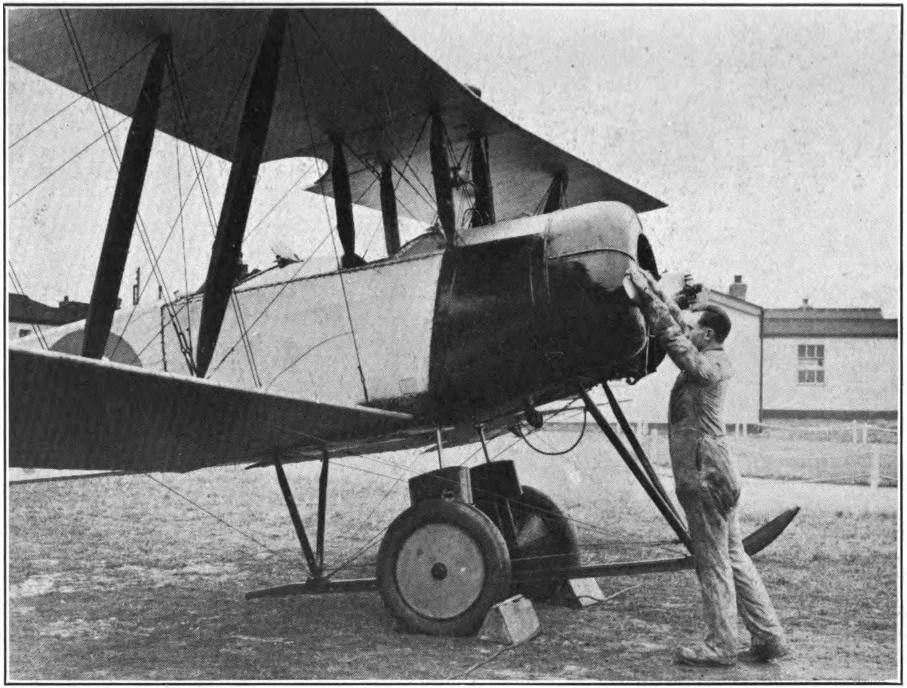


FIG. 54.

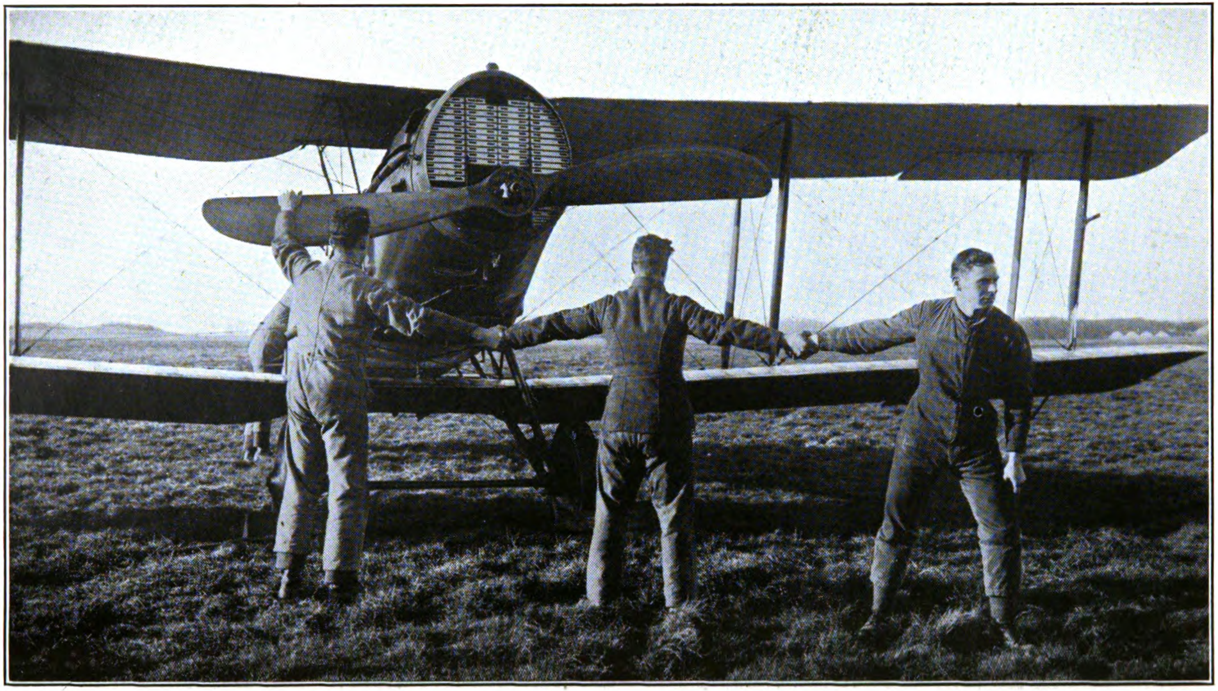


FIG. 55.

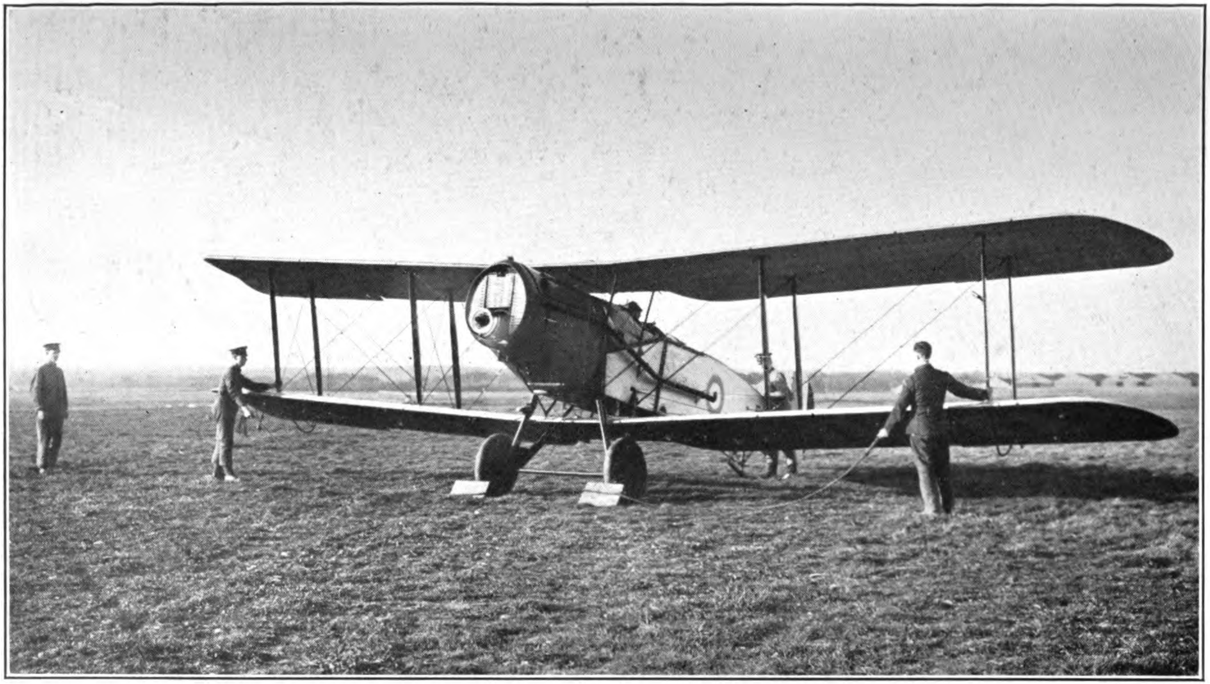


Fig. 56.

the signal " All clear," and the pilot, after retarding his spark, must give " switch off," " petrol on," " suck in." The Hucks starter is then put into action. The switch must not be put at contact until sufficient petrol has been sucked in and the engine is revolving fast enough to prevent a back-fire. As soon as the engine starts the Hucks starter is driven clear.

147. For training purposes the drill for swinging air-screws laid down in Appendix I must be followed. C.Os. are responsible that airmen receive adequate training on the lines laid down in this drill.

Removal of chocks.

148. After the pilot has run up his engine and is ready to take off, he must signal to this effect by waving his open hand from side to side, through an angle of 180°, the arm being fully extended above the head. The chocks must at once be pulled clear of the wheels by the airmen holding the cords, who must then double round to the rear of the planes and hold on to the rear outer inter-plane struts. The airman at the tail will stand clear. The airman in charge, having ascertained that (i) the aerodrome is clear for taking off, (ii) no other aeroplane is about to land or take off, (iii) the mechanic on the tail is clear, must salute the pilot. This salute is to be taken as an " all clear " signal and must be given whether headgear is worn or not. The pilot must acknowledge the salute, and if he desires to take off at once, wave his arm fully extended above the head. The mechanics on the wing tips must at once stand clear. (*See* paras. 206, 207, and figs. 59 to 64.)

(Para. 149)—PROCEDURE FOR SWINGING AIRSCREWS.

Action by.	Sequence of action taken.						
	*1.	*2.	3.	4.	5.	6.	7.
				(i) *Engine with no self-starter.*			
Pilot	—	" Switch off-suck-in."	—	—	" Contact "	—	If airscrew fails to start the series 1 to 6 is repeated, omitting the words "suck in" if not required.
Mechanic	Standing clear, " Switch off-suck in."	—	Swings airscrew to suck in.	Standing clear, " Contact."	—	Swings airscrew.	—
				(ii) *Mono-engine.*			
Pilot	(b) " Switch off-petrol on."	(d) " Petrol off-suck in."	—	—	" Contact "	—	
Mechanic	(a) " Switch off-petrol on."	(c) " Petrol off-suck in."	Swings airscrew to suck in.	Standing clear, " Contact "	—	Swings airscrew.	

(iii) *Engine with self-starter where swinging is not necessary.*

Pilot	—	" Switch off-suck in."	—	—	" All clear-contact."	Manipulates self-starter.	—
Mechanic	Standing clear, " Switch off-suck in."	—	Swings airscrew to suck in.	Standing clear, " All clear-contact."	—	—	—

(iv) *Engine with self-starter where swinging is necessary.*

Pilot	—	" Switch off-suck in."	—	—	" Swinging contact."	—	Turns starting handle on mechanic saying " three."
Mechanic	Standing clear, " Switch off-suck in."	—	Swings airscrew to suck in.	Standing clear, " Swinging contact."	—	Holding airscrew 'One-two-three-Go.' Swings airscrew on " Go."	—

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* Where engines are supplied with a means of advancing and retarding ignition, the words " Spark retarded " is always to be inserted before the words " Switch off " in columns 1 and 2.

THE RUNNING AND MAINTENANCE OF AERO-ENGINES.

General considerations.

150. Although the maintenance and repair of aero-engines requires the employment of highly skilled personnel, and is dealt with in full detail in separate handbooks, it is essential that a pilot should possess not only a theoretical knowledge of the working of engines used in service aeroplanes, but also a comprehensive practical acquaintance with their care and running, both on the ground and in the air.

151. The construction and general working principles of internal combustion engines are dealt with in Chapter VI. The present section contains instructions for the running and maintenance of aero-engines and for the detection and diagnosis of faults by sound and other symptoms. The chief points of maintenance are given under the four general headings, ignition, fuel, lubrication and water circulation; and the fault-finding table, while not designed to cover the possible faults of all types of aero-engine, provides a means of tracing the causes of the troubles to which the internal combustion engine is most frequently subject.

Starting.

152. A pilot must never start up a type of aero-engine that is unfamiliar to him until he is satisfied that he thoroughly understands its petrol pressure system and other peculiarities. The rules for inspection immediately prior to flight, as given in para. 116, must be observed; the pilot must further ascertain that the engine is in running order, that chocks are in position, that the aeroplane is head to wind, and that dust will not be blown into the sheds or on to other aeroplanes when the airscrew is revolving. He should turn on the petrol and place the throttle in position for sucking in; this position varies according to the type of engine and the temperature of the day, but an opening of from one-quarter to one-third will usually be sufficient. If it is necessary to dope the engine to facilitate starting, a small quantity of petrol (in cold weather slightly more petrol may be required than in warm) should be injected with the dope pump or syringe. The petrol may be introduced into the induction manifolds through a special atomising nozzle-jet, or in rotary engines, direct into the cylinders. A very rich mixture is thus provided for the first few firing strokes. If the engine, instead of starting, gives a few weak and laboured explosions, it is probable that it has been too richly doped; the airscrew should be turned a few revolutions before an attempt is again made to start.

153. If a rotary engine has been standing for over 48 hours, a syringeful or more of oil should be introduced into the crankcase, and the engine turned by hand for a few revolutions to distribute it. If, when a rotary engine is being started, the petrol should burst into flame, the cylinder in which this occurs must be turned at once to top dead centre and the flame thus prevented from spreading to the crankcase. The button switch must never be used for starting up.

154. Should a radial engine not fire on all cylinders after starting up, it should be tried out at full throttle before a remedy is sought by changing the plugs. Oil tends to collect in the lower cylinders, but is soon cleared when the engine is running.

Precautions to be taken before running up.

155. As soon as an engine has been started it must be throttled down and kept running as slowly as possible without misfiring (about 600 r.p.m.). During this period the pilot will ascertain that the pulsator or oil pressure revolution indicator and air or petrol pressure gauge are operating properly. Incorrect oil pressure readings are occasionally caused in cold weather by congealed oil in the pipe leading to the oil pressure gauge. An oil cock is sometimes placed between the oil tank and the oil pump, and care must be exercised to ensure that this cock is turned on. When the engine starts it will be noticed that the oil pressure first rises rapidly, and then as the oil gets warmed up gradually falls till it remains steady at the correct running pressure. This is due to the fact that when the engine starts the oil is thick and does not circulate freely when pumped; in cold weather the reading may be so high as to require the throttling down of the engine to keep the pressure within the safety zone. If the pressure does not commence to drop after a few minutes' running, the engine must be stopped and the cause of the trouble investigated; even though there may be no obstruction in the system, there is a risk of the oil failing to pass some of the smaller ducts and oilways. Where oil tanks are placed below the oil pump, priming may be necessary.

156. The radiator shutters in a water-cooled engine should be kept closed until the temperature of the water reaches 75° C.; the engine is then ready for running up, provided that the oil pressure is down to normal.

157. A rotary engine must be warmed up gradually for a period of two to three minutes; when it has been ascertained that the oil is circulating, the engine is ready for running up. The fine adjustment need only be opened when sucking-in is actually being performed or when the engine is running.

158. If the engine is fitted with dual ignition the pilot will run it on each unit separately to test whether regular running is obtained with each.

Running up.

159. If the engine has variable ignition, the lever should be advanced and the engine gradually accelerated until the throttle lever reaches the fully opened position. An engine should not be kept running at full speed on the ground for a longer period than is required for the needle to give a steady reading; but it is better to give an adequate ground test than to take-off with a fault in the fuel, oil or ignition system which may not show itself in a comparatively brief run-up. Special care must be exercised with air-cooled engines, and the maximum periods for ground test specified by the makers should never be exceeded; the amount of petrol used, moreover, must be kept down to the minimum, or blueing of the cylinders may result. In all engines, any tendency to exceed the maximum number of revolutions a minute may indicate that an unsuitable airscrew has been fitted.

160. When the engine has been run up and the pilot is satisfied that vibration is normal and that the number of revolutions a minute is satisfactory, he should throttle down to the lowest R.P.M. consistent with even running. He must ensure that the engine is actually throttled down to the minimum, as in some engines the throttle is stopped so as to prevent its completely closing; any error in the setting of this stop may not be disclosed until after the engine has been completely warmed up.

161. Whilst the engine is running-up the pilot must pay close attention to any signs of engine trouble. A minor repair or adjustment may prevent serious difficulties developing during flight. Any symptom of knocking must be investigated immediately and the engine not run again until the cause has been discovered. A very smoky exhaust may denote faulty lubrication or incorrect carburation. Other symptoms during running-up are given in the fault-finding table in para. 172.

162. If a rotary or radial engine is left to stand after testing, the sparking plugs from the lower cylinders should be removed to allow the oil to drain. If an engine employing an air pressure system is not required for an hour or so after testing, the air pressure should be released from the tank by opening the cock on the hand pressure pump. This will relieve the system generally and obviate the risk of a flooded engine should the main petrol cock be opened inadvertently.

Engine maintenance.

163. Cleanliness is as important in the maintenance of aero-engines as it is in the care of aeroplanes. The exterior of the engine, no less than the interior, must be kept scrupulously clean. Not only may accumulated dirt cause overheating, but it may hide faults in the metal and may lead to serious defects in running. The exterior of the engine, and of integral parts such as magnetos, plugs and carburettors, should be cleaned with paraffin and greased with engine oil to prevent rust. With rotary and radial engines a stiff brush is required, and it is better to clean parts such as cylinders and valve springs while the engine is still hot. When not actually in use the engine must be covered with a sheet of heavy fabric, which will give protection against damp and dust.

164. The points for percentage inspection briefly indicated in para. 115, together with the unit routine inspection orders, should be used as a guide to keep engines up to a high standard of maintenance. Adjustments should only be made when they are justified; the cause of indifferent performance must be properly investigated and the faults eliminated one by one. Log-books, if the entries are correct and up to date, are of the greatest value in keeping a careful check of an engine's proper maintenance.

Ignition.

165. The ignition system must never be interfered with unnecessarily; only the maintenance specified in the detailed instruction books is to be carried out. Magnetos must be kept warm and dry, and in continuously damp weather it may be necessary to maintain a constant change, the set not on the engine being kept in a warmed cupboard. Lubrication of magnetos must be effected with clean and fairly thin oil, which should be applied sparingly, and in accordance with the detailed instructions issued for each type of engine. In rotary engines the H.T. leads to sparking plugs must be taut, but not in tension; the plugs require special care, and it may be necessary to use two sets alternatively, a change being made after each flight.

166. The useful life of sparking plugs may be considerably lengthened by proper cleaning. When an engine is oily, the plugs will require daily washing, and a more thorough cleaning approximately every twenty flying hours. In a very clean engine, habitually run on a moderately weak mixture, it is possible that the plugs may not require thoroughly cleaning over much longer periods, although they must be inspected at regular intervals and should be occasionally washed. Plugs that remain quite clean in flight may become fouled

up while the aeroplane is landing and taxying-in at low power; they should be removed while still hot and soaked before the fouling has dried and hardened. Plugs that cannot be dismantled may be cleaned by soaking for some hours in spirit to loosen the fouling, and by the use of a stiff bristle brush to remove the deposit as completely as possible from the mica and the body. Plugs that have been used in engines run with mineral lubricating oil should be soaked in petrol or benzole; plugs fouled with castor oil should be soaked in alcohol (methylated spirit) instead of petrol. When plugs are being fitted or removed a suitable box spanner must be used, and care taken that it is not pulled over against the insulator, which may otherwise be damaged.

Fuel.

167. Petrol tanks must be filled immediately after flight; if they are left empty overnight, water is liable to accumulate gradually in the tanks as a result of condensation. Petrol must always be filtered through gauze. Rust or corrosion on tanks must receive immediate attention. A petrol tank must not be repaired until it has been pumped out with air and left for some hours for the fumes to evaporate. Petrol must not be allowed to leak into the fuselage; to prevent this a tray should be fitted below the float chamber.

168. Where more than one carburettor is employed, absolute synchronisation in the adjustment of the throttle barrels is essential. The filtering gauzes must be periodically dismantled and washed in paraffin with a stiff brush; rags may not be used for this purpose.

169. The altitude control must be so adjusted that when an engine is running on the ground with throttle fully open the maximum number of revolutions a minute is obtained with the altitude control closed. It should never be opened under normal atmospheric conditions below an altitude of from 3,000 to 4,000 ft.

Lubrication.

170. When oil tanks of stationary engines are filled, allowance must be made for oil already in the sumps. Oil must always be filtered through a funnel with a fine mesh gauze strainer reserved for this purpose only. This funnel must not be left lying about the hangar, but must be kept away from dust, preferably in a cupboard.

Water circulation.

171. The water should be drained off at each overhaul, and a solution of warm water and caustic soda poured in,

The engine should be run with this for about fifteen minutes, then drained off, filled with clean water, run again for fifteen minutes, and again drained and refilled. Engines with aluminium water-jackets require a solution of warm water with thirty per cent. paraffin, since soda has a detrimental effect on aluminium. When radiators are being filled, cold water should never be added to hot, as airlocks may be caused. Rain-water should be used, if available. The cocks should be left open until water issues freely, then closed and securely wired.

AERO-ENGINE FAULT-FINDING TABLE.

172.—(i) Difficulty in starting.

1. Guiding symptom.	2. General cause.	3. Defect.	4. Remedy.
(*a*) Explosions in carburettor (ignition being in order).	Weak mixture -	(1) Engine not running fast enough.	
		(2) Atmospheric temperature very low; engine very cold.	Fill radiator with hot water; corrects itself as engine warms up.
		(3) Altitude control cock open or leaking.	Ensure good fitting control cock.
		(4) Insufficient priming.	
		(5) Air leaks in induction system; leaky compression cocks, valves or plugs.	Tighten all bolts on joints; tighten plugs; renew C.A. washers; fit new plugs.
		(6) Petrol level too low in diffuser; damaged or sticking float needle or toggles; collar displaced.	Check level; test needle for truth and for free action in guide; note that float is sound and that toggles and lever work freely; if collar is displaced determine petrol level and reset afresh.
		(7) Air locks in petrol pipes; chocked jet, pipe or filter; dirt or water in carburettor.	Drain off and examine petrol system and determine cause.
(*b*) Carburettor floods; smoke from exhaust pipes.	Rich mixture -	(8) Petrol level too high, through leaky float; dirty needle-valve seating; worn needle; needle sticking.	Shake float, listening for petrol inside: repair or replace with new one; grind in needle valve with metal polish; clean needle or ease guide slightly.
		(9) Excessive priming or hand-flooding.	With throttle open, turn engine six times.

		(10) Enlarged slow-running jet	Replace jet with one of correct size, or, if variable, adjust correctly.
		(11) Diffuser or jet not properly screwed home.	
(*c*) Uneven resistance when engine is turned.	Compression weak in one or more cylinders.	(12) Valve or valves stuck open	Remove and clean the stems with paraffin; if stem is warped renew valve, grinding in with paste mixed with small quantity of oil.
		(13) Carbon or dirt on valve face.	
		(14) No tappet clearance	Correct the adjustment.
		(15) Valves burnt or distorted	Replace any valves that are distorted or burnt.
		(16) Leaky piston rings	Examine pistons for worn or displaced rings.
		(17) Piston head cracked or broken.	
		(18) Leaky compression cocks	Grind in with metal polish or renew.
		(19) Loose or leaky sparking plugs	Screw up or fit new C.A. washer; fit new plugs.
(*d*) Engine does not fire at all.	No spark at plugs	(20) Switch in "off" position.	
		(21) Switch defective	Examine toggles and spring, contact fingers and terminals.
		(22) Switch wire from magneto to switch chafed through and "earthed."	Examine run of wires.
		(23) Contact breaker lever bush seized on pivot; spring broken; platinum-tipped screw slackened; earthing button inside cover, spring broken or adrift; insulation of contact screw carrier block defective.	Remove lever, ease bush with special reamer; replace spring; readjust contacts to 0·010–0·012-in. gap; replace cover of spring. Change contact-breaker.

AERO-ENGINE FAULT-FINDING TABLE—(*contd.*)

1. Guiding symptom.	2. General cause.	3. Defect.	4. Remedy.
		(24) Winding of armature or coil broken down; internal lead or connection broken; slip ring or H.T. pick-up faulty.	Replace by new magneto.
		(25) (Coil ignition only). Accumulator run down or disconnected.	Recharge accumulator and make up electrolyte in accordance with detailed instructions on label.
(*e*) Engine kicks backwards at starting.	Ignition	(26) Timed too early on drive; hand-control too much advanced.	Re-time on drive; retard by hand-control.
		(27) Two or more H.T. leads crossed to plugs or distributor terminals.	Trace leads and check firing sequence.
		(28) Magneto distributor gears wrongly meshed.	Remove magneto, re-mesh gears correctly.
		(29) Badly carbon-tracked distributor.	Clean with petrol on rag; if burnt, clean up with fine glass-paper; emery-cloth or metal polish must not be used; carbon brush may be wiped clean.
(*f*) Engine stops after a few revolutions.	Fires only while hand-starter magneto is in use.	*See* Nos. (20), (21), (22), (23), (24), (25).	
	Weak mixture	*See* Nos. (2), (3), (4), (5), (6), (7).	
		(30) Air leak from float chamber to choke.	Trace to defective joint; re-make joint.
		(31) Air leak pipe stopped up.	
	Rich mixture	*See* Nos. (8), (10), (11).	

(ii) **Irregular or bad running.**

(*g*) Misfiring, knocking and explosions in carburettor and exhaust pipes.	Ignition	*See* Nos. (27), (28), (29).	
(*h*) Misfiring on certain cylinders only.	Ignition	(32) Dirty or defective plugs	Clean or change plugs.
		(33) Plug gaps too wide or too narrow.	Set gaps correctly. Average best setting is 0·015 in.
		(34) Loose plug or distributor terminals.	Check over and tighten, but use no undue force.
		(35) Insulation of H.T. leads perished, particularly when fitted in metal conduit.	Examine leads for cracks and perishing; watch for sparking to "earth" while engine is running.
	Uneven compression.	*See* Nos. (12), (13), (14), (15), (16), (17), (18).	
	Mixture	*See* No. (5).	
(*i*) Irregular misfiring on all or any cylinders.	Ignition	*See* Nos. (3), (29), (30), (32), (33), (34), (35).	
		(36) Distributor pick-up, carbon brushes or springs broken or missing.	Fit new brushes or springs; ensure that they are free in guides.
		(37) Contact-breaker lever bush partly binding on pivot, or much too loose; gap wrongly adjusted.	Ease bush with special reamer, or fit new lever; adjust gap to correct setting, *i.e.*, 0·010 to 0·012 in.
		(38) Contact breaker cam-ring very loose on seating.	Ensure correct fitting, and, if necessary, fit new parts, and readjust contacts as necessary.
		(39) Sparking over outside of plug insulator (usually only at full load); sparking from plug or cable terminal to cowling or earth.	Check gap of plug points, which may be too wide; see that there is at least ⅛ in. air gap to "earth."
		(40) Safety gap set too close	Should be 7½ to 9 mm., according to type.

AERO-ENGINE FAULT-FINDING TABLE—(*contd.*).

1. Guiding symptom.	2. General cause.	3. Defect.	4. Remedy.
(*j*) Misfiring at low revolutions.	Weak mixture -	*See* Nos. (1), (2), (3), (5), (6), (7), (30), (31).	
	Rich mixture -	*See* Nos. (8), (10), (11).	
	Uneven compression.	*See* Nos. (12), (13), (14), (15), (16), (17), (18), (19).	
	Faulty ignition -	*See* Misfiring symptoms (*h*) and (*i*) above.	
(*k*) Misfiring at low revolutions.	Weak mixture -	*See* Nos. (2), (3), (5), (6), (7), (30), (31).	
		(41) Main jet partially choked -	Blow through jet or clean with petrol; never with wire; drain off float chamber and petrol wells.
	Faulty ignition -	*See* Misfiring symptoms (*h*) and (*i*) above.	
(*l*) Loss of power and reduced revolutions at full throttle.	Weak mixture -	*See* Nos. (3), (5), (6), (30), (31).	
		(42) Air intake or pressure balance pipes shielded or cut off at wrong angle.	Cut off intake and pressure balance pipe mouths at angle of 30° approximately to slip-stream; if either pipe mouth is shielded from the slip-stream, lengthen it or carry it clear of the obstruction.
(No actual misfiring)	Rich mixture -	*See* Nos. (8), (11), (41).	
	Bad compression -	*See* Nos. (13), (15), (16), (18), (19).	
	Faulty ignition -	*See* Nos. (32), (33).	
		(43) Ignition timing insufficiently advanced.	Advance more by hand control.

(*m*) Loss of power and reduced revolutions at full throttle. (With knocking)	Overheating	*See* Nos. (26), **(42)**.	
		(44) Sparking plug electrodes overheated.	Try alternative plugs with less open "mouths" or stouter electrodes.
		(45) Shortage of water.	
		(46) Water pump not working properly; pipes choked.	Examine stuffing glands. Cleanse system in accordance with instruction.
		(47) Unsuitable lubricating oil.	
		(48) Oil pump nct working properly; pipes or filter choked.	Look for leaks in pipe line. Especially note that there are no air leaks on suction side of pump. Note that flanged joint and washer are sound and that the pressure relief valve is in order.
		(49) Cylinders, pistons or valves carbonised.	
	Weak mixture	*See* Nos. (2), (3), (5), (6), (7), (30), (31).	
(*n*) Knocking	Pre-ignition	*See* Nos. (44), (45), (46), (47), (48), (49).	
	Loose or worn parts or bearings		Replace or take up wear.
	Weak mixture	*See* symptom (*l*) above.	
(*o*) Vibration	Misfiring	*See* symptoms (*i*), (*j*), (*k*), (*l*).	
	Airscrew	(50) Airscrew warped or out of balance.	Test airscrew for truth.
		(51) Loose airscrew boss	Remove airscrew; look for scoring on shaft; having replaced airscrew, tighten up securing nut and make sure that locking device is secure.
	Engine	(52) Unbalanced reciprocating parts, due to incorrect assembly.	Strip and reassemble correctly.
		(53) Loose holding down bolts or faulty engine mountings.	Examine spring washers; note that bolts are sound.

AERO-ENGINE FAULT-FINDING TABLE—(*contd.*).

1. Guiding symptom.	2. General cause.	3. Defect.	4. Remedy.
	Rough running without misfiring.	(54) Faulty mixture and poor distribution; cold induction system; incorrect tappet clearances; carburettors not synchronised.	
(*p*) Engine continues to fire after switching off, but fires regularly.	Ignition	(55) Switch wires broken or adrift	Trace wires and examine terminals, etc.
		(56) Contact breaker cover dropped off; earthing button spring broken; button badly worn and very dirty.	Examine, clean or replace as required.
(*q*) Engine continues to fire after switching off, but fires irregularly.	Ignition	(57) As (55) or (56), but still making some connection to earth.	As above for (55) and (56).
	Overheating	(58) Plugs, valves, etc., overheated (engine soon stops).	*See* section (*m*).

ENGINE PRECAUTIONS IN COLD WEATHER.

General Precautions.

173. Unless engines are treated with special care in cold weather, not only may great difficulty be experienced in starting-up through the low temperature of the petrol, oil and water, but considerable damage may be done through the oil and water freezing.

174. Under average winter conditions, the following general precautions should therefore be taken :—

(i) *Water-cooled engines.*—Water must be completely drained out of tanks and pipes immediately after flight, and whilst the engine is still warm.

(ii) *All engines.*—Catalytic lamps are to be placed near the oil pump. The engine must be protected with a quilted engine cover.

175. Under conditions of exceptional cold, the following additional precautions are necessary :—

(i) The lubrication system must be drained off.

(ii) Plugs must be kept in heated cupboards, and placed in the engine only when required for flight. Plug holes must never be left open; unserviceable or dummy plugs should always be screwed home.

(iii) Magnetos must be kept in dry cupboards, and changed as frequently as possible.

Starting.

176. In cold weather, difficulty is experienced in starting an engine owing to the petrol in the carburettor being too cold to vaporise, or because it condenses in the induction pipe before reaching the cylinder. This difficulty can be overcome by warming up the carburettor and induction pipes with rags soaked in hot water, or by doping the engine with petrol that has been warmed in hot water. An engine must run for a longer period on the ground in cold weather than in warm, so that it may warm up thoroughly before it is opened out. Sometimes it may be found that the engine is difficult to move by hand, owing to the congealing of the oil in the cylinders, piston rings and exhaust valves. The oil may be rendered fluid by injecting a little paraffin into the cylinders, but care must be taken not to inject too much or the cylinders may be scored when the engine is started. A little paraffin injected into each cylinder while the engine is still warm after a flight will prevent the oil from congealing.

Water.

177. The water must be run out immediately after flight. The airscrew must be rotated for about a minute after the

radiator has been emptied, in order to ensure drainage of the whole water-cooling system. The water run off should be kept and used again, as if fresh water is used for each filling scale will form in the radiator and water-jackets. Filling the radiator with boiling water will ease an engine in which the lubricant has become congealed; but in exceptionally cold weather, hot water is essential, as if cold water is used it may freeze before the engine is started. When hot water is used, the pump drain cock must be left open for some seconds before the airscrew is moved; if this precaution is not observed, the pump spindle, if frozen, may shear. All external water pipes are liable to freeze up, and must be wrapped with asbestos string. Taps and pressure-release valves may freeze up during the night and must be tested before flight.

178. There is a variety of anti-freezing solutions that may be used with advantage, such as a mixture of one part of methylated spirit to three of water. Losses caused by evaporation during flight tend to weaken the solution, and these losses may be made good with a mixture containing an increased proportion of methylated spirit. Losses due to leakage or overflow may be made good with a mixture in the original proportions.

Oil.

179. It is necessary to ensure that all oil is drained away from tanks, pumps and pipes. When castor oil is used, methylated spirit must be syringed through the pipes after the oil has been run out. The tank must be filled with oil warmed to a temperature of 40° to 50° C., care being taken that it penetrates through to the oil pump. The oil is to be heated by placing oil cans in hot water and not by direct contact with a flame. Hot oil must be injected into parts that are not directly lubricated.

ACTION TO BE TAKEN AFTER FORCED LANDING.

Safeguarding the aeroplane.

180. A pilot's actions after a forced landing will be influenced by the reasons that have caused him to descend. If he has landed to repair a minor defect, or for any cause that will allow him to proceed on his flight in a short time, he must, before stopping his engine, taxy to the leeward end of the landing ground and manœuvre his aeroplane into position for taking off. If, however, he anticipates a stay of some duration, his aeroplane must be taxied or moved by hand to the leeward of such shelter as a haystack, house, or hedge, and there left standing head to wind. If there is

no wind at the time of landing, the pilot must ascertain the local prevailing wind, and peg down his aeroplane accordingly.

181. Whenever a pilot lands on grounds other than an Air Force aerodrome he will be held entirely responsible for the proper protection and safeguarding of his aeroplane. He is not to leave it except under guard of a responsible person, but must nevertheless take steps to report by the quickest available methods to the C.O. of the nearest Air Force unit, and having once established communication must consider himself under this C.O.'s orders. He must remain responsible for his aeroplane, however, until relieved by an Air Force guard.

182. If the landing has occurred in the vicinity of a military barracks or encampment, the C.O. of the nearest unit may be asked to provide a temporary military guard. Should no troops be available, the nearest police office must be approached for a police guard; and should it be found impossible to procure either an army or police guard, the services of suitable civilians may be requested.

Restriction of damage to private property.

183. When a landing has been made in a hay or corn field, where the crop is well advanced in growth, it will usually be found impossible to fly out. In such circumstances it will cause less damage if the aeroplane is man-handled to the nearest gap in the hedge or gate, and there dismantled. If the aeroplane is too large, or the ground too heavy, every care must be taken while dismantling to limit the area of damage to a minimum, and breakdown parties must be instructed to this effect. If the crop is thin or not well advanced, it may be advisable to fly the aeroplane out, but extensive taxying must be avoided, as a large area of the crop will thereby be damaged. If possible, the aeroplane should be man-handled to the take-off point. (Instructions as to the handling of aeroplanes are given in paras. 125–128.) The same principles apply if the landing is effected in a "root" field, but here, if taxying is decided upon, the movement should be parallel to, and not across, the "drills."

184. Spectators must be kept under adequate control, otherwise they may cause far more damage to crops and hedges than the aeroplane; and until the guard arrives assistance should be obtained from the owner or occupier of the land or a few capable members of the crowd.

Examination of aeroplane.

185. If the landing has been necessitated by engine failure or other defect, the pilot must immediately investigate the cause and extent of the trouble, and decide whether he

is capable of remedying it without skilled assistance. He must not arrive at this decision without carrying out a systematic inspection of engine and aeroplane, so that he may determine not only the cause of the engine trouble, but whether his aeroplane has sustained damage in landing.

186. When assistance is required to render the aeroplane serviceable, the pilot must carry out his examination with a view to supplying the following information:—

(i) Cause of failure and extent of damage.

(ii) Whether the aeroplane when repaired can be flown away from the forced landing ground.

(iii) Spare parts required to render the aeroplane serviceable.

(iv) Time required to carry out the necessary repairs (*i.e.*, whether the aeroplane can be rendered serviceable for flight the same day).

(v) Amount of petrol and oil left in the tanks.

(vi) Any special tools required for repairs.

In making his report a pilot must be careful not to underestimate his requirements nor to state that his aeroplane is repairable on the spot when dismantling would prove more expedient, otherwise unnecessary journeys and loss of time will result.

Communication with the nearest Air Force unit.

187. When the pilot has satisfied himself on these points, and has fixed his position accurately on the map, he must leave a responsible guard in charge of the aeroplane and communicate with the nearest Air Force headquarters by telephone or telegraph. In addition to the particulars listed in para. 186, he must give the type and number of his aeroplane, his rank, name and unit, his telephone number and most accessible address, and must state whether a guard and picketing tackle are required for the night. He must exercise the utmost care in giving his location clearly and accurately, and arrange to meet the breakdown party at a well-defined spot that can be referred to by map, such as a post-office, inn, church, or cross-roads.

Pegging down and protecting the aeroplane.

188. An aeroplane must always be pegged down for the night, however settled the weather may appear at the time of landing. The general principles for picketing an aeroplane in the open, as laid down in paras. 129–133, are to be followed as far as possible, but if the required implements are not obtainable, a mallet, stakes and ropes can usually be borrowed locally; and pending the arrival of an Air Force guard, the

pilot must improvise adequate protective measures to the best of his ability.

189. Having placed the aeroplane in the most sheltered position available, head to wind, the pilot must picket each wing down in turn, making use of the ring bolts fitted for the purpose on the underside of the lower planes. A rope must then be tied round the tail-skid, or over the fuselage just in front of the tail unit, and attached to pickets driven in on either side of the tail-skid; the rope over the fuselage must be passed over sacking, hay, or other suitable material, to prevent damage to the fabric. As an additional precaution, the axle should also be picketed. All pickets or pegs must be driven firmly into the ground, but a certain amount of slack must be allowed on the rope so as to permit the aeroplane to rock slightly. If the night is stormy, or if the shelter is not considered entirely satisfactory, it may be advisable to place the aeroplane in flying position by "digging in" the wheels and raising the tail on a suitable support. The weight of the fuselage must rest on the longerons immediately beneath the cross members, and the tail must be picketed firmly down so as to secure this position.

190. Cart covers, tarpaulins, blankets and similar material should be obtained and the engine, airscrew and pilot's cockpit effectively covered. It is important to protect airscrews from the heat of the sun, which tends to warp them, especially when they are damp after rain. If the weather is cold and there is no prospect of immediate departure, oil and water must be drained from their respective tanks and systems while yet warm.

CHAPTER III.—AIRMANSHIP IN THE AIR.

GENERAL CONSIDERATIONS.

Principles of flying training.

191. The fundamental principles of manœuvre and control are similar in all types of aeroplanes and seaplanes. For purposes of instruction this publication contains reference to the Avro aeroplane, in which most pupils are at present taught to fly.

192. In flying training, moral and confidence are the basis of all successful work; it should, therefore, be a primary object to instil into pupils a feeling of security in the air. Instruction in flying differs from most other forms of teaching in the measure of responsibility which the

instructor is bound to assume. An error on his part may not only destroy the self-confidence of his pupil, but in an extreme case may have fatal results.

Method of instruction.

193. The art of flying can only be imparted to a pupil by means of a process of systematic instruction in an aeroplane. This instruction is carried out by means of dual control, which can only be effective if the pupil is constantly made to realise that he has complete control, and that his instructor is there to tell him what to do, and, as necessity arises, to show him how to do it.

194. Communication between instructor and pupil by speaking tube or telephone is essential, and should be simple and efficient, so that the instructor can be heard clearly and easily understood. By means of the telephone the instructor can point out any mistakes made by the pupil whilst flying, and need not interfere with the control of the aeroplane more than is absolutely necessary.

Sequence of instruction.

195. The sequence of instruction indicated in Chapter IV., para. 351 of this manual will be carried out when pupils are being trained *ab initio.* Pilots under training as flying instructors at the Central Flying School are taught to instruct in accordance with this sequence.

Methods of recording a pupil's progress.

196. Each instructor should maintain a chart upon which the progress of his pupils is shown graphically. This chart should show clearly the respective amount of dual and solo flying carried out on each type of aeroplane, and should at the same time record all " crashes " and forced landings, with a note as to their causes. The graph should illustrate :—

(i) The amount of flying carried out on successive days by the pupil.

(ii) Actual flying time.

(iii) The respective amount of solo and dual flying, and the various types flown.

This graph can best be drawn up on squared paper, by taking horizontal units to represent successive days, and the vertical units twenty minutes' flying time. The difference between dual and solo flying is shown on the graph by broad or narrow lines, respectively, and different types of aeroplanes are represented by colours. This method of recording pupils' flying training will enable a unit commander to supervise and compare the progress made by individuals, and will, moreover, often give him a clue to the cause of a "crash."

Use of instruments.

197. Pupils should be taught to fly as much as possible without using instruments, relying rather on their own senses for information as to air speed and side-slip. If a pilot gets into the habit of relying absolutely on instruments, he may find himself in serious difficulties in the event of their failure or inaccuracy. For cloud or night flying, however, instruments are essential, and the pilot should know the correct indications of all instruments, so that a single glance over his instrument board will give him all the possible information. A few notes on the more usual instruments are added below :—

(i) *Aneroid.*—Used for indicating height above ground level at which it has been set. Pilots must remember that the indication is *not* the height above the ground that they are actually flying over. Alteration of indication is sluggish, and in a quick descent (*e.g.*, a spin) is often quite different from the actual loss of height.

(ii) *Air Speed Indicator.*—The pilot should practise estimating the speed of the aeroplane by the feel of the controls and the sound of the wind, which to an experienced pilot are more reliable than the Air Speed Indicator.

(iii) *Cross level.*—Used to indicate skidding or side-slipping in turns. At first it may be helpful to the pilot to check his turns by this means, but he should accustom himself to feeling the pressure of his body on the seat, which is just as accurate a guide and more reliable.

Engine instruments.

198. Generally speaking, these should be used at all times, but the pilot should make a point of studying the sound of the engine, which to a trained ear conveys much useful information.

(i) *Air pressure gauge.*—Indicates pressure in the fuel tank or tanks, or petrol pressure at the carburettor. This should be looked at occasionally during flight and at once in the event of engine trouble. If the failure is due to stoppage of fuel supply the engine may be restarted on another tank. The pupil should practice changing from one tank to another when at a reasonable height, 3,000 to 4,000 feet, so that he does not get flurried when he has to do so at a low altitude.

(ii) **Oil pressure gauge*.—As the oil circulation in the engine depends on the pressure, this should be watched continually. Cases have occurred in which, when oil gauges have failed in the air, the pilot has made a forced landing at once, although the engine showed no signs of overheating. This might lead to an unnecessary crash. It is desirable, under the circumstances, to continue the use of the engine for a short time for the purpose of selecting alternate forced-landing sites.

(iii) **Oil thermometer*.—This should be watched, and if the temperature gets high, the flight should be abandoned.

(iv) *Pulsator*.—Used in place of an oil pressure gauge, with rotary engines. Though not indicating actual pressure the correct functioning of the oil pump can be seen by watching the pulsation in the glass.

(v) *Revolution indicator or tachometer*.—Indicates the speed of the engine crankshaft. The pilot should listen carefully to the sound of the engine at different speeds, and with practice he will know whether the engine is running properly without the use of this instrument, which is not always reliable.

(vi) **Water thermometer*.—This indicates the temperature of the water cooling the engine, and as the efficiency of the engine largely depends on temperature, this instrument should be continually watched and the temperature maintained by the use of the radiator shutters. (*See* chapter on engine running.)

Fire.

199. If an engine catches fire in the air, the pilot should at once

(i) turn off the petrol.
(ii) open the throttle full.
(iii) switch off, after the engine has ceased firing, but not before.

Height should be lost by side-slipping, as far as possible, to prevent the petrol fumes and smoke from overcoming the pilot, and the flames from spreading down the fuselage.

TAXYING.

Action of controls whilst on ground.

200. The greatest care should be exercised in starting an engine and in running it whilst taxying, otherwise great

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* Not fitted in "Avro" training aeroplanes.

strain is brought to bear on the crankshaft and other parts. The engine controls should always be manipulated gently, and all rapid movements of the throttle should be avoided. When an aeroplane is taxying, the air speed is very low and the effect of the controls correspondingly slight, so that the pilot manipulating his controls must use them fully and coarsely. The rudder lies in the path taken by the slip-stream, and its effect varies according to the strength of the slip-stream passing across it. While taxying it may be necessary to increase momentarily the effect of the rudder by " opening up " the engine, thereby increasing the speed of the slip-stream passing over the rudder.

Swinging.

201. Some aeroplanes have a tendency to swing their tails round as soon as a turn is commenced, and this is particularly noticeable when taxying in a heavy beam wind. To keep an aeroplane straight while taxying, the pilot must not only correct any tendency to swing, but must actually anticipate the swing by quick and coarse application of the rudder, the effect of which may be increased by opening the throttle. The ailerons can be used to supplement the rudder on the ground. For example, if an aeroplane begins to swing to starboard, full control to starboard will lower the port ailerons, which will act as a brake on the port plane.

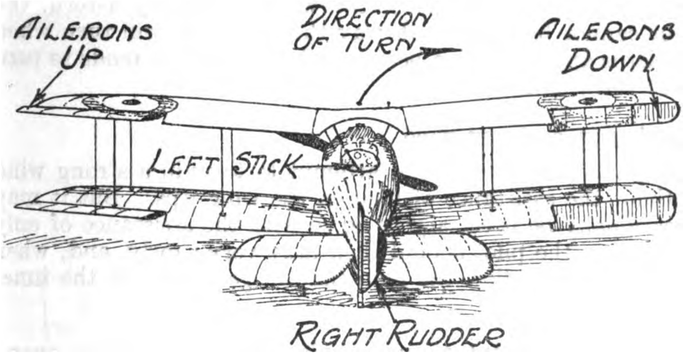

FIG. 57.—Aileron Control on Ground.

Peculiarities of various types.

202. Aeroplanes vary considerably in their behaviour whilst being taxied :—

(i) Two-seater aeroplanes fitted with uncontrolled tail skids have an especial tendency to swing, which must be checked, as explained in para. 201. Aeroplanes of this type are more easily steered by putting the control column forward and thus relieving the tail-skid of some of the weight; but if this is done care should be taken to check any sudden upward movement of the tail.

(ii) Two-seater aeroplanes fitted with controllable tail-skids are easier to taxy, and answer more readily to movement of the rudder bar. This is due to the tail-skid being connected to the rudder and being manipulated with it.

(iii) Some aeroplanes, if they strike an obstacle on the ground whilst taxying fast, have a tendency to turn up on their noses; the control column should therefore be kept right back in order to "anchor" the tail to the ground. This does not apply to taxying down-wind in rough weather, when the control column should be held forward to keep the elevator down and to prevent the wind from getting under the tail.

(iv) Most twin-engined aeroplanes are steered on the ground by means of the engines (*i.e.*, one or other engine is opened up according to the direction of the turn).

Taxying down-wind.

203. Control can be maintained more easily when an aeroplane is taxying in a down-wind direction if the wind be kept on either quarter. If the wind is directly astern, the pilot cannot be sure which way the aeroplane will turn when rudder is applied. In a beam wind an aeroplane tends to turn in to the wind.

Taxying in a strong wind.

204. A pilot should not attempt to taxy in a strong wind without the assistance of men on the wing tips. But it may occasionally be necessary to do so with the assistance of only one man; the pilot should then taxy very slowly, and, when about to turn, allow the man time to get round to the inner wing tip.

Action in the event of an aeroplane tending to blow over.

205. When landing or taxying across a strong wind, a pilot should exercise the greatest care to prevent an aeroplane (particularly a single-seater aeroplane) from blowing over. If the wind lifts the port wing and the aeroplane shows a tendency to turn over, full opposite aileron and rudder to starboard must be applied, and the aeroplane should at once be swung down-wind. If the aeroplane is pointing down-wind the pilot should hold the control column forward to prevent the wind from getting under the tail, and wait for assistance

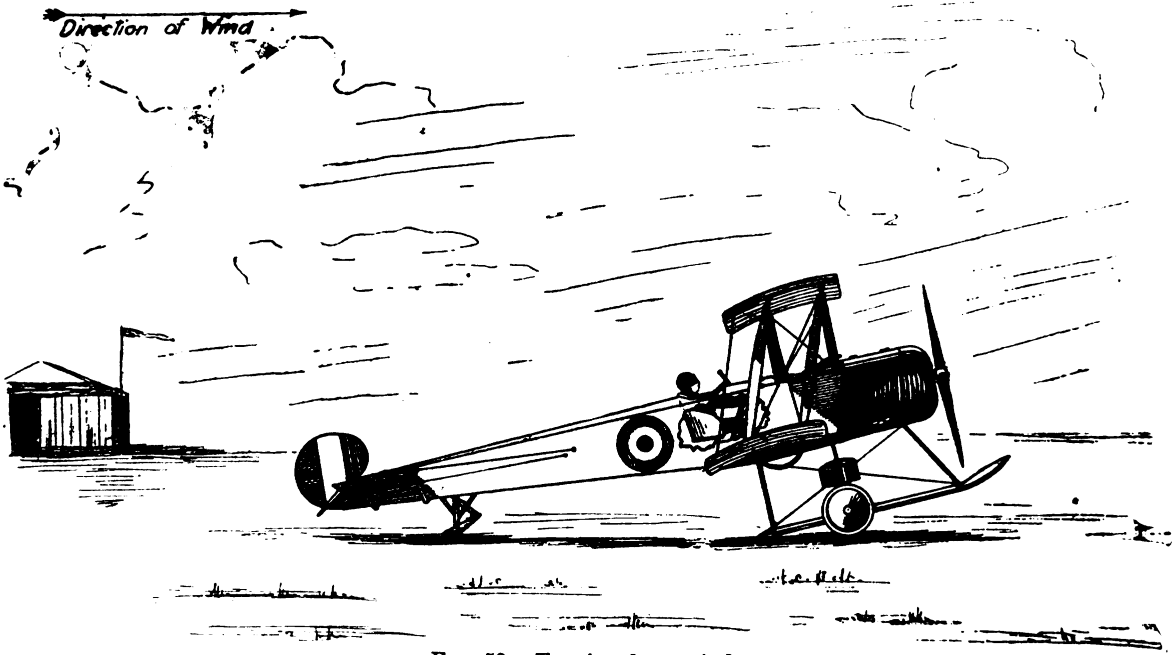

FIG. 58.—Taxying down wind.

Precautions for safety on the ground.

206. The following precautions for safety must be carefully noted :—

(i) Aeroplanes taxying must not exceed the speed of a man walking and must be accompanied by a mechanic if there is much wind. The aeroplane must stop whenever another aeroplane is in the act of taking off or landing.

(ii) Before taking off, pilots must assure themselves that the air in the immediate vicinity is clear; if an aeroplane is about to land they should wait until the landing has been effected.

(iii) The first aeroplane to get into position has priority for taking-off over all other aeroplanes.

(iv) Before landing, pilots should assure themselves that the aerodrome is clear and that landing can be effected without danger.

(v) The aeroplane at the lowest altitude has priority for landing.

(vi) Immediately after landing the pilot must bring his aeroplane to rest and look round the aerodrome and sky before beginning to taxi.

(vii) Pilots must make definite signals to the mechanics when taxying.

Communication between pilot and airmen on the wing tips.

207.—(i) The following visual signals are used by the pilot in giving his orders while sitting in the pilot's seat :—

(*a*) "*Chocks away.*"—Hand waved slowly from side to side, arm fully extended, the hand to be open and to come down as low as the shoulders on either side.

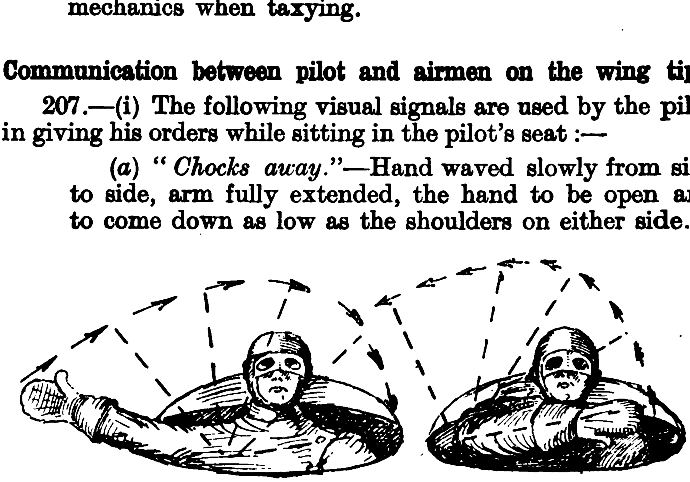

Fig. 59.—Chocks Away. Open Hand at arm's length waved slowly from side to side in line with the Shoulders.

(*b*) "*Stand clear.*"—The hand waved above the head. When this signal is being given, care should be taken that it is clearly visible to the man standing by the tail as well as to those at the wing tips.

(*c*) "*Stop.*"—Arm raised to the full extent above the head, hand open with palm to the front.

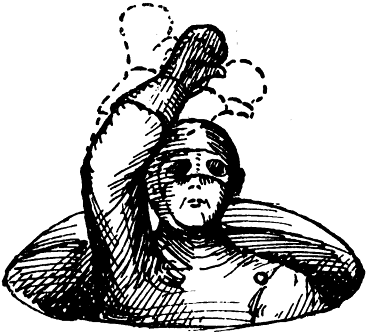

Fig. 60.—Stand Clear. The Hand waved above the Head.

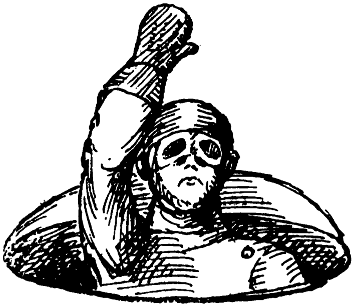

Fig. 61.—Stop. Arm raised to full extent above the Head, Hand open, Palm to the Front.

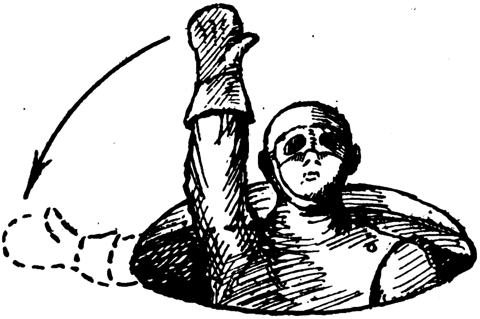

Fig. 62.—Change Direction. Arm moved from vertically upwards down into line with the Shoulder in the direction the turn is to be made

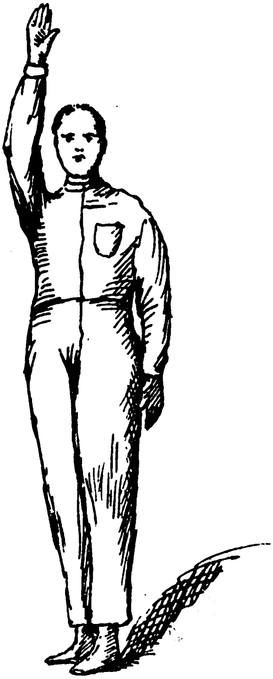

FIG. 63.—Stop. Arm raised at full extent above the Head.

(*d*) "*Change direction.*"—Arm moved from vertically upwards down into line with the shoulder in the direction in which the turn is to be made.

(ii) The following signals are used by airmen when communicating with the pilot:—

(*a*) "*Stop.*"—The arm raised at full extent above the head.

(*b*) "*All clear.*"—The airman at the wing tip, after ascertaining that there is no obstacle in the way or any aeroplane about to land, salutes the pilot, meaning that the course is clear for taking-off. (For this purpose the airman salutes, whether he has his headgear on or not.)

PRINCIPLES AND EFFECT OF CONTROL IN THE AIR.

Speed in relation to control.

208. The controls of an aeroplane do not begin to take appreciable effect until a certain minimum speed has been attained, nor do they all acquire their maximum power at the same speed. As speed increases the rudder is the

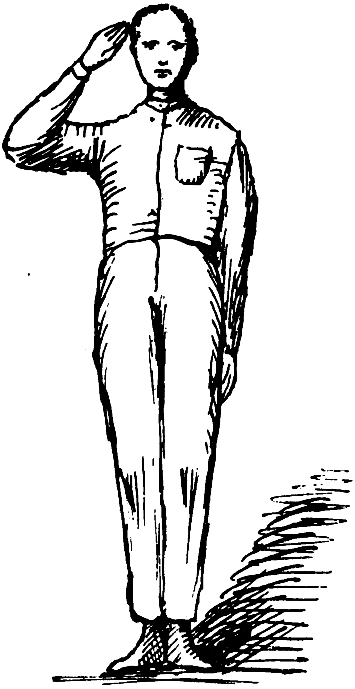

FIG. 64.—All Clear. Mechanic Salutes Pilot (no headgear required).

first to take effect on most aeroplanes, then the elevator, and lastly the ailerons. As flying speed is lost, the ailerons are first to lose effect, then the elevator, and lastly the rudder. Forward speed can be maintained by engine power or by loss of height, and the pupil must realise the importance of keeping speed in order to maintain control.

Use of the elevator.

209. The effect of using the elevator on the aeroplane is always the same whatever its position in relation to the ground, so that when the control column is pulled back the path of flight is changed along a positive curve in the "looping plane," or plane of symmetry. When the control column is pushed forward (*see* fig. 20) the path of flight is changed along a negative curve in the looping plane (*see* para. 24).

Use of ailerons.

210. If the control column be moved to one side and kept in this position, and the rudder held in a central position, the aeroplane will bank to that side, commence to

side-slip and ultimately swing its nose down towards the same direction. It will be noticed that the nose of the aeroplane at first swings in the opposite direction to that in which the control column is moved. This is due to the aileron drag on the "rising" wing. The ailerons are also used to regain lateral trim when this has been lost, owing to disturbed air conditions.

Use of the rudder.

211.—(i) The rudder always acts in a plane at right angles to that of the elevator. Its effect on an aeroplane in flight varies with the speed. When the engine is running at full revolutions the effect of the rudder will be much greater than when the aeroplane is gliding without engine.

(ii) As a general rule, rudder should always be applied gradually in the air, since the effect, particularly when the engine is running, is very powerful, and a sudden coarse application of this control may change the path of flight so quickly that the aeroplane will lose flying speed and stall.

(iii) An attempt to turn by the use of the rudder without banking towards the direction of the turn causes an aeroplane to skid outwards. The effect of this skid is to increase the drag, and therefore to reduce the speed of the aeroplane. Owing to the dihedral angle of the planes, and the fact that the outer wing is travelling faster than the inner wing, thereby getting more lift, the aeroplane will eventually bank in the direction of the turn. A correct turn therefore is made by the combined use of rudder and ailerons, the combination being so regulated that a skid will not result.

The "feel" of the controls.

212.—(i) The faster an aeroplane travels, the firmer become the controls, and *vice versa*, until when the speed is so low as to approach that at which the aeroplane will "stall," the controls become "sloppy"; or in other words the control column can be moved with greater ease with little effect on the aeroplane. "Sloppy" controls are a symptom of low flying speed and a warning signal to the pilot that the aeroplane is about to stall. On the other hand, so long as an aeroplane responds readily to the ailerons, its flying speed is sufficient.

(ii) A correct appreciation of the sensitiveness of the controls is essential to safe and accurate flying, because it is through his "flying sense" that the pilot can readily distinguish when the aeroplane is travelling at the speed best suited to the execution of a certain manœuvre. For instance, if, when endeavouring to climb through a cloud, the pilot feels the controls rather stiff, he will realise that the speed is too high even without consulting his instruments. Only by cultivating delicate and appreciative "hands" will the pilot develop that flying sense which is the secret of successful flying.

(iii) An aircraft fitted with camber gear flaps is less sensitive on the controls and does not respond to the controls so quickly when the flaps are set at full camber or incidence; the pilot is therefore more liable to stall the aircraft inadvertently. Special care must be taken when turning with camber gear flaps set at full incidence, and sharp turns at a low altitude should never be made with camber gear so set.

Flying straight and level.

213. Viewed from the pilot's seat of an aeroplane in flight on a clear day, the earth appears to be divided from the sky by the horizon. Irrespective of his height above the earth, an imaginary line drawn from the pilot's eye to the horizon forms an approximate tangent to the curve of the earth. A point on the horizon can therefore be used as a guide to determine the angle of the path of flight relative to the ground; moreover, since the horizon forms a circle of which the pilot is the centre, it can be used (i) as a guide to level flying in whatever direction the aeroplane is being steered, and (ii) to ascertain the correct inclination of the aeroplane while climbing or gliding by observing the apparent position of the nose above or below the horizon. For example, when an aeroplane is climbing, its nose appears to be aligned with a point in the sky which remains at a constant height above the horizon for each angle of climb. When the instructor demonstrates the correct angles of climb and glide, the pupil should note the position of the nose relative to the horizon.

214. The apparent position of the nose of an aeroplane with relation to the horizon will vary slightly, and will depend on :—

(i) The type of aeroplane being flown;
(ii) The position of the individual pilot's head in relation to the nose of the aeroplane; and
(iii) The nature of the horizon in view.

In misty weather the true horizon may be obscured, and the circle which the pilot may imagine to be the horizon is in reality formed by mist or clouds. The experienced pilot subconsciously makes allowance for these variations, and the pupil should learn to exercise his judgment, and to develop his "flying sense" by an intelligent use of the horizon in combination with the other aids to flying.

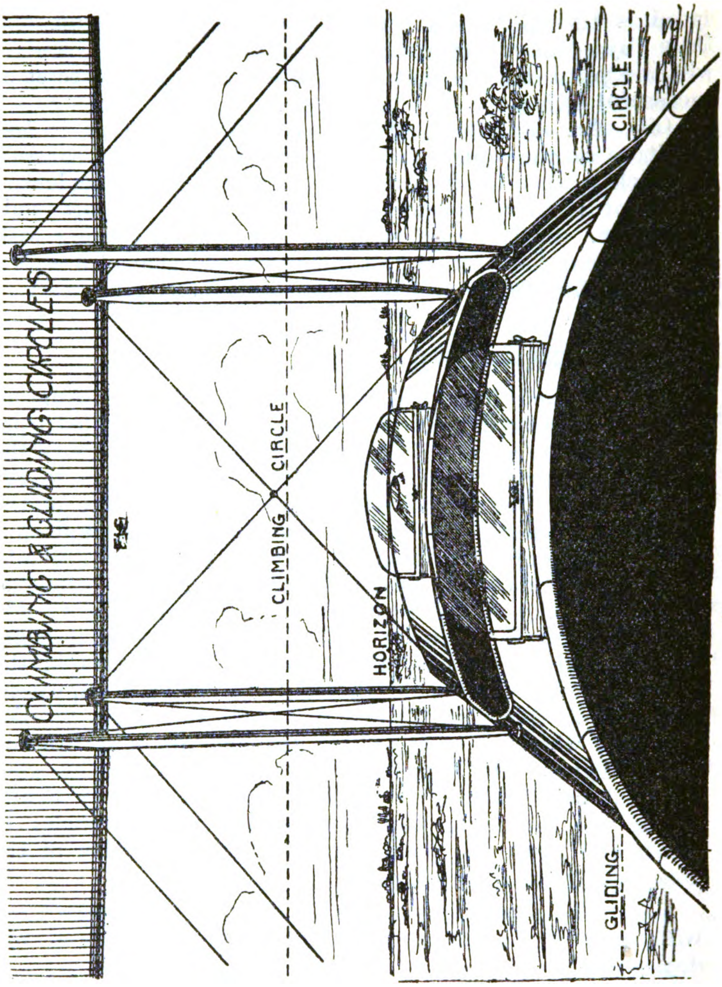

FIG. 65.—Flying Position.

215. The horizon can also be used for checking lateral trim. When an aeroplane is in level flying position the horizon is seen to cut the outer struts on both sides at an equal height above the lower plane. If the aeroplane is banked, one wing tip sinks below the horizon, while the opposite one rises above it. If in straight flight the pilot observes that the wing tips are not of equal height above the horizon, the aeroplane is not trimmed laterally. In order to gain lateral trim, the control should be moved towards the higher wing tip.

Straight flying.

216. When an aeroplane is trimmed laterally, the rudder controls direction. To keep an aeroplane straight and prevent it from yawing, a distant landmark or cloud-point in the sky should be selected, and the direction maintained with reference to it. With a somewhat analogous function to that of the submerged surface of a sailing boat, an aeroplane possesses a keel surface, acted upon by the air, which gives it directional stability. The keel surface resists side-slipping or skidding and tends to keep the aeroplane on its course.

Climbing.

217. The maximum rate of climb is attained by raising the nose so that the axis lies at a positive angle to the horizontal. The size of this angle depends upon the type and rigging of the aeroplane, power of engine and altitude. Every aeroplane has an "optimum" climbing angle at which it will climb at the greatest rate. If it is inclined at too steep an angle it will not gain height, and if the angle be still further increased it will lose flying speed, stall, and dive. An experienced pilot can gauge approximately the best climbing angle of an aeroplane by the feel of the controls. Although the best climbing angle varies with altitude, it can always be found approximately by climbing at the steepest angle consistent with the retention of full control. This angle can be found by pulling back the control column until the ailerons cease to have much effect, then allowing the nose of the aeroplane to drop until full aileron control is regained. The aeroplane will then be approximately at its best climbing angle.

Effect of altitude.

218. Both the rate of climb and the angle that the aeroplane makes with the horizontal decrease as altitude increases. The density of the air diminishes with increasing altitude; the engine-power required increases as the square root of the density, until an altitude is reached at which the power available is just equal to the power required, and above which altitude the aeroplane will not climb. This altitude is known as the "ceiling of the aeroplane." In order to keep the aeroplane at its maximum altitude, it is necessary to fly it at a considerable angle of incidence, an angle which is in fact its "optimum" climbing angle at that elevation, or rather at that density.

Stalling.

219. An aeroplane will only fly provided that it is moving through the air at a forward speed above a certain minimum

speed, which varies for each aeroplane and according to the load carried. This velocity is known as "flying speed." When an aeroplane loses flying speed while in the air, its controls lose grip, it becomes uncontrollable, and will fall until it regains the necessary speed. The condition resulting from loss of flying speed is known as "stalling." There is no reason why an aeroplane should not be slowed down and stalled, provided there is sufficient height in which to recover control during the resultant dive, for all modern aeroplanes will, when stalled, fall automatically into a nose dive from any position. As soon as the aeroplane has regained sufficient speed the controls will again become effective, and the simple operation of pulling back the control column will then raise the nose and bring it back into the normal flying position. It must be borne in mind however that an aeroplane requires an appreciable time to recover lost speed after stalling, and may therefore fall several hundred feet before coming under control. For this reason great care should be exercised to maintain flying speed at low altitudes. Moreover, if the pilot attempts to counteract the tendency to dive by holding back the control column, the aeroplane will take longer to recover flying speed, and will consequently fall a greater distance out of control. Pupils should practice stalling the aeroplane at safe heights until they become conversant with the feel of the controls at and near stalling point.

Gliding.

220. When the engine is cut off, flying speed is maintained by losing height, consequently when engine power is reduced the nose must be lowered to compensate for loss of speed. As soon as the engine stops running, the nose must be put down until the aeroplane is gliding through the air under gravity with sufficient speed to support itself upon a descending path of flight. The angle made by the gliding line with the horizontal is called the gliding angle, and is gauged by :—(i) the "feel" of the controls, (ii) sound, and (iii) the air speed indicator.

221. When the engine is cut off there is a certain difference in the feel and effect of the rudder and elevator owing to the absence of slip-stream, and these controls must therefore be used more coarsely to obtain the same effect. There is no appreciable difference in the effect of the ailerons during a glide. The lateral balance is no longer influenced by torque, and in the Avro the port wing will appear to have a little too much lift, and the aeroplane will tend to glide with the starboard wing down.

222. The intensity and quality of the sound made by the impact of the air against the planes and wires will

indicate to an experienced pilot that he is gliding too quickly or too slowly. The gliding angle can be found approximately by first putting down the nose of the aeroplane until the aileron control becomes heavy and stiff and the noise of the wind in the wires becomes very loud. The aeroplane is then gliding too fast. If the nose is raised until the aileron control ceases to have effect, the aeroplane will then be gliding too slowly. If the nose is then dropped to a position between gliding too fast and too slow, until full aileron control is regained, the aeroplane will then be gliding at approximately its best gliding angle.

TAKING OFF AND LANDING.

Taking off into wind.

223. An aeroplane should never be taken-off across or down-wind unless, owing to the presence of obstacles on the aerodrome or for any other reason, it is impossible to take off up-wind. A pupil with dual control may however practice taking-off both across and down-wind after he is thoroughly capable of taking off up-wind. (*See* figs. 66, 67 and 68.) If an aeroplane is pointing into a 20 m.p.h. wind, it acquires the same amount of lift as if it were travelling at 20 m.p.h., and will therefore require 20 m.p.h. less ground speed to lift itself into the air when taking off. In spite of this advantage plenty of room should be allowed in case of difficulties; the aeroplane should therefore be taxied to the leeward side of the aerodrome and turned directly into wind.

224. When once the aeroplane has been taxied into position, the throttle should be opened slowly with one hand, whilst the control column is pushed forward with the other. The action of pushing the control column forward depresses the elevators and thus helps the tail to lift off the ground. As the tail rises to the horizontal the control column must be eased back; otherwise the tail may rise too high and the airscrew touch the ground. If this horizontal position is maintained accurately the aeroplane will, owing to the incidence of the planes, lift itself off the ground without further action on the part of the pilot. The aeroplane should be held level with the ground at a height of two or three feet until it has gained sufficient speed to be put into its correct climbing angle. Even then the climbing angle should only be assumed gradually by easing the control column back slowly and gently (*see* fig. 66).

225. Lateral trim must be maintained by manipulating the ailerons, and direction by manipulating the rudder. In

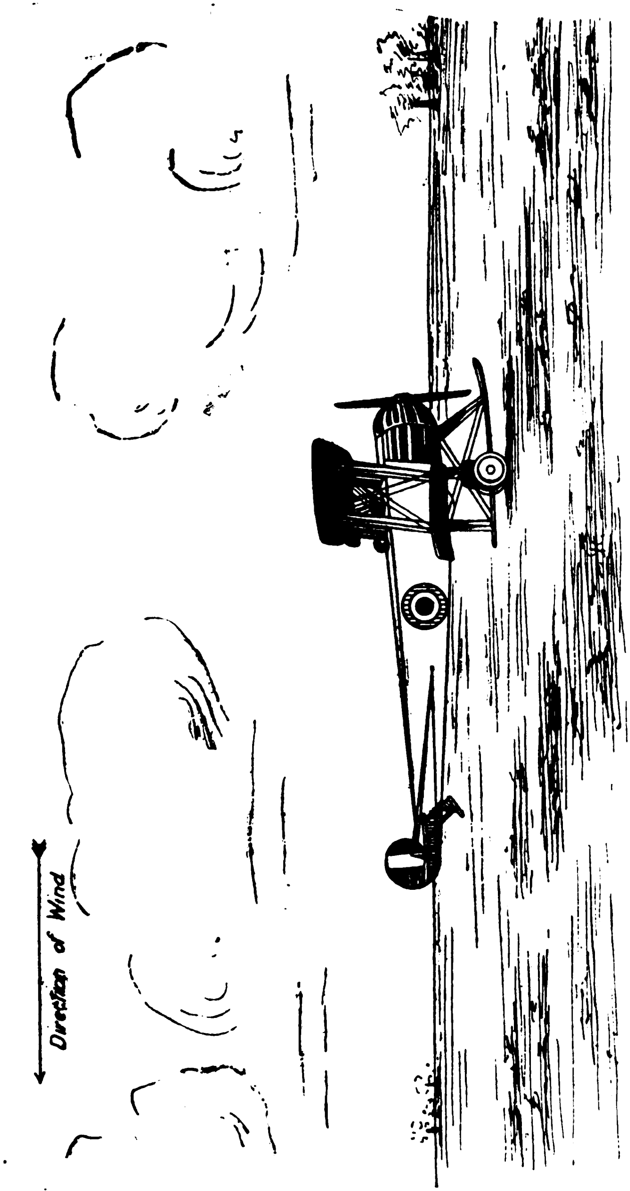

FIG. 66.—Taking off. Correct position.

taking-off over uneven ground the aeroplane may bounce off before it has gained flying speed, and will consequently drop again, causing it to hop. This must be avoided as

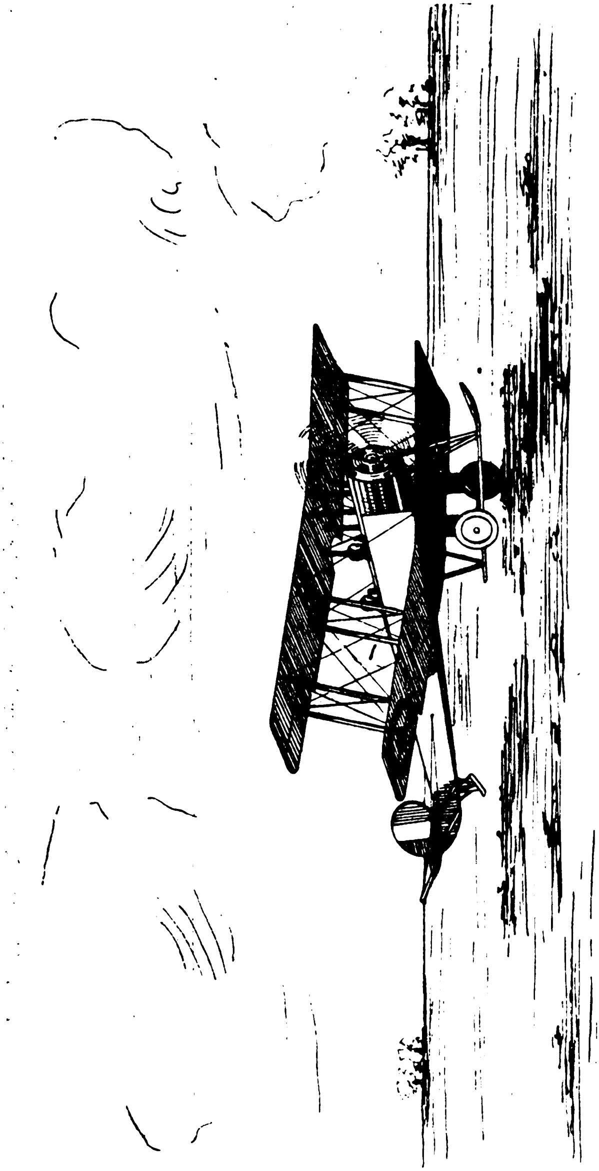

FIG. 67.—Incorrect method of taking off.

much as possible by choosing a smooth path for taking off, or, if the ground be ridge and furrow and the wind allows, by running in a direction parallel to the ridges. If rough ground cannot be avoided, the aeroplane should be pulled off the ground as soon as possible, and when off it should be flown a foot or two above the ground until sufficient speed is attained before setting it at the correct climbing angle. As speed is gathered, the control column should be

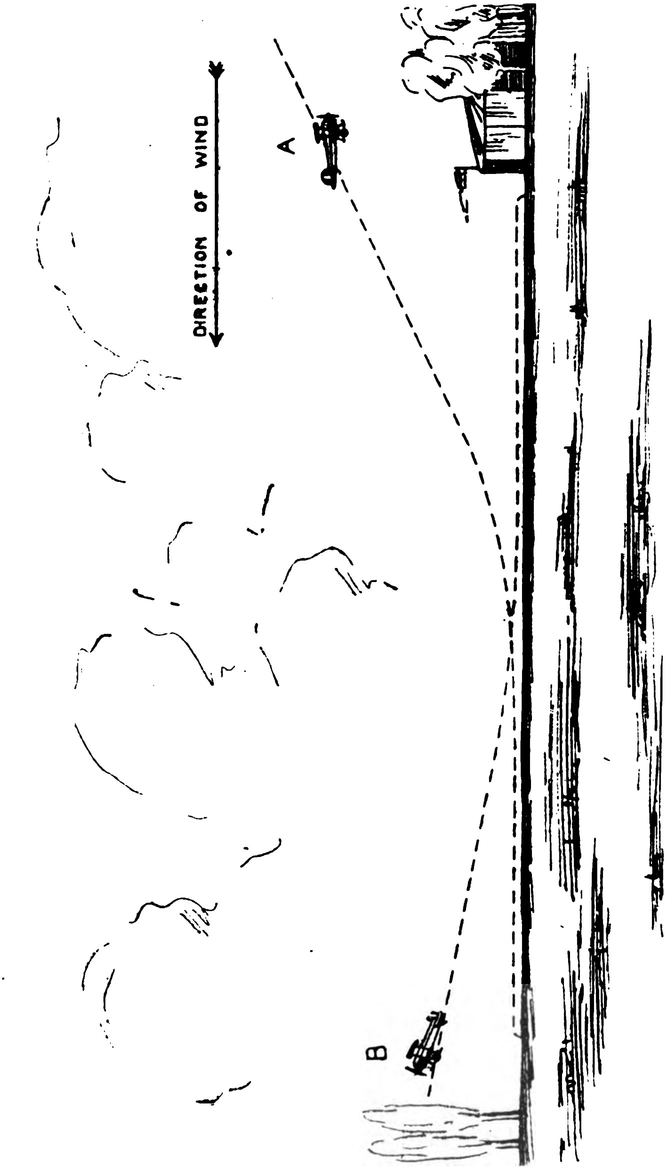

FIG. 68.—Taking off. Effect of wind on path of climb when taking off.

slowly centralised until the climbing position described above has been attained. Great care should be taken by the pilot to guard against stalling while performing this manœuvre, the tendency being to climb before sufficient speed has been attained.

226. As already stated (para. 206), the pilot must be quite certain that the course is clear before taking-off, and that no other aeroplane is about to land or take-off in the vicinity of his course. On a tractor aeroplane with the tail down the pilot can seldom see directly ahead, and should therefore detail someone to signal "all clear" (*see* para. 207 (*b*)). In order to keep the aeroplane straight, it is essential to look ahead and fix on an object by which to maintain direction. This will help the pilot to recognise the slightest swing and to check lateral trim. The elevator should be used to raise the tail into its correct horizontal position as soon as the engine is opened out; when once the tail is up, the effect of the rudder increases, and directional control is thereby facilitated.

Judging distance.

227. When approaching an aerodrome the pilot should previously check the direction of the wind. Landing into wind reduces the speed at which the aeroplane travels over the ground; the aeroplane will therefore come to rest in a shorter space than if it be landed out of the wind. Cross-wind landings should only be attempted for practice or in an emergency. To land down-wind increases the speed at which an aeroplane travels over the ground; it therefore requires a much larger landing space, and increases risk of damage to the undercarriage and aeroplane.

228. In order to land at any particular spot the pilot must first manœuvre his aeroplane into the correct position relative to its gliding angle, the height, and the distance from the landing ground. This position is dependent on the strength and direction of the wind, which should be determined as soon as possible during the descent from the wind indicator, smoke or bunting. Failing these, the aeroplane should be flown in several directions and the drift noted.

229. Judgment of distance can only be perfected by constant practice. The pilot must know how far the aeroplane will glide for a given loss of height. Constant practice will enable him to estimate the effect of the wind in causing the aeroplane to overshoot or fall short of the mark. To practise this the pilot should approach the landing ground choosing some mark to land on. When he thinks he is in a suitable position he should shut off the engine and glide down in a straight glide and land, noting his distance from the mark.

He should then note the speed of the wind for future reference and make due allowance when making another approach.

Losing height.

230. Having determined the direction of the wind, the pilot must select the portion of the aerodrome on which he intends to land. The pilot should first of all manœuvre the aeroplane to the leeward side of the landing ground, and then lose height by gliding backwards and forwards across wind, always turning towards the landing ground and never away from it. By this means the landing ground can be kept in sight. By gliding across wind the pilot should be in a position at any time to execute a turn into wind and land. He should keep a few hundred yards to leeward of the landing ground so that after his final turn he will have room to lose any surplus height by side-slipping.

Landing.

231. When flying at a high altitude, a pilot has no near objects by which speed may be gauged; the pupil must therefore first accustom himself to the sensation of speed on approaching the ground. Landing is virtually a glide terminating in a stall, and so regulated that the stalling point is reached with the wheels about two feet above the ground. The aeroplane should be made to glide down normally until about ten feet from the ground, when the control column must be eased back gently until the aeroplane is flying horizontally. If the aeroplane be held in this position, *i.e.* parallel to the ground, by gradually easing the control column further back a satisfactory landing will result. (*See* fig. 69.) The aeroplane should then be kept straight, by coarse use of the rudder. The backward movement of the control column which causes the aeroplane to "flatten out" should be one continuous movement, which pupils and pilots must endeavour to perfect. "Pump handling," *i.e.*, pulling the control column back and then pushing it forward, is bad flying, indicates bad judgment and should be avoided.

232. When an aeroplane is landing in a high wind, the ground should be approached with a little more than normal landing speed. If the pilot executes a fast landing he retains full use of his controls until the aeroplane is completely landed, and can counteract the effect of a sudden gust of wind.

TURNING.

Turns up to 45° (with engine).

233. The turn is the most difficult manœuvre, and at the same time one of the most essential manœuvres, to

teach. A pupil will not be able to turn correctly until he has thoroughly grasped the relative effects of the rudder and elevator with regard to the ground, and these depend upon the angle of bank of the aeroplane. No turn can be correctly accomplished without making use of all three controls in conjunction—rudder, elevator and ailerons. It will be realised therefore that it is not possible on paper to describe in detail the action that a pilot should take to enable him to execute any correct turn in the air, but the principle upon which his actions depend can be explained, and the practical application of these principles can be demonstrated in the air.

234. The turn will vary from a very wide circuit with a small angle of bank to a rapid turn with a greater angle of bank, on the circumference of a relatively small circle. A correct turn cannot be made without banking the aeroplane inwards sufficiently to overcome the natural tendency for it to skid outwards on the application of the rudder. Speed is lost very rapidly if the aeroplane is allowed to skid, owing to the retarding effect on the keel surface. Skidding or slipping while in a turn, indicated by side draughts on the face, shows that the turn is not being executed correctly and that the controls are not being used in correct proportions. It is necessary therefore to demonstrate how the effect of rudder and elevator upon the aeroplane, with regard to the ground, vary according to the angle of bank. The pupil must be made to realise that, whatever the position of the aeroplane, the effect of the controls relative to the aeroplane itself does not vary. They must be used in correct conjunction to prevent skidding or side-slipping.

Rudder.

235. With the aeroplane flying horizontally and with the control column central, the application of rudder forces the nose straight around the horizon (for the moment neglecting gyroscopic action). To demonstrate this apply a slight left bank, hold it, and apply left rudder. The nose travels round the horizon but drops slightly. Increase the bank and hold it in various stages up to the almost vertical position. The application of rudder in either direction will show that, as the bank increases, so the rudder becomes more and more effective in controlling the position of the nose vertically, with regard to the horizon.

Elevator.

236. With the aeroplane flying horizontally and with the rudder central, the application of elevator forces the nose straight up or down with regard to the horizon (again

neglecting gyroscopic action). To demonstrate this apply a slight left bank, hold it, and ease the control column back. The nose will rise, but will travel slightly around the horizon

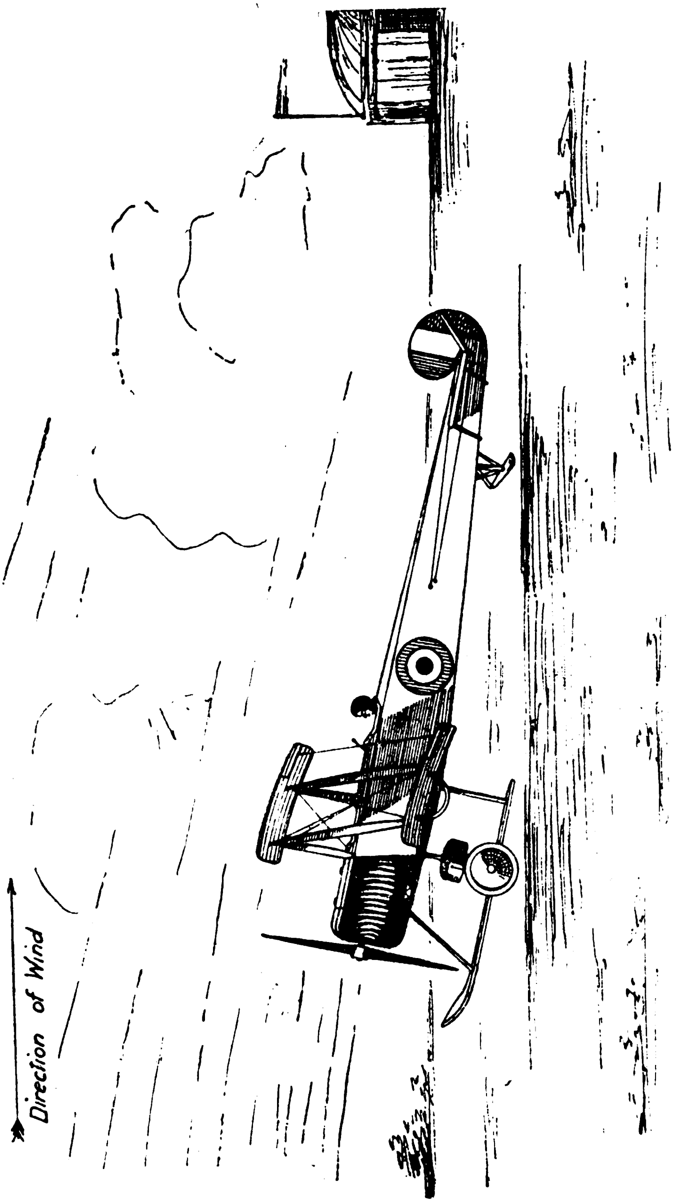

FIG. 69.—Correct Tail-down Landing

in the direction of the bank. Increase the angle of bank and hold it in various stages up to the almost vertical position, and the application of elevator either fore or aft will show that, as the bank increases, so the movement of the elevator will develop a greater tendency to control the path of the nose around the horizon.

237. The turn is made up of the combined effect of aileron, elevator and rudder and can be divided into three parts, going into, staying in, and coming out of the turn.

Going into the turn.

238. The aeroplane must first of all be flown straight and level. To make a gentle turn to the left, apply left bank and left rudder together. The bank applied prevents the aeroplane from skidding outwards owing to the application of rudder. Plenty of rudder is required to begin with, not only to commence the turn, but also to counteract the aileron drag tending to force the nose to the right owing to the application of left bank. The aeroplane now commences to turn, and therefore a little rudder may be eased off. It will be noticed that the bank tends to increase itself owing to the planes on the outer side having to travel faster than those on the inner side, and thus getting more lift (fig. 71). To prevent this bank must be held off. Holding off the bank transfers the aileron drag from the outer to the inner wing tips, which helps to increase the rate of turn. More rudder must now be taken off; but as the aeroplane is on a bank, the amount of rudder applied is tending to send the nose down, and so in order to counteract this, the control column must be slightly eased back.

239. In a turn to the left, gyroscopic action tends to make the nose rise, so bottom (*i.e.* left) rudder must be kept on. But in a turn to the right the tendency is for the nose to drop rapidly; this must be checked by application of top (*i.e.* left) rudder, and to a very small extent by slightly easing the control column back. The application of top rudder tends to reduce the rate of the turn.

Staying in the turn.

240. (i) The nose of the aeroplane must be kept turning around on the horizon, by the combination of rudder and elevator.

(ii) Should the nose rise above the horizon, the control column must be eased forward; but as this slows up the rate of turn, it must be counteracted by the application of bottom rudder.

(iii) The greater the angle of bank the faster must be the rate of turn. If the rate of turn is slow for the angle of bank, the aeroplane will side-slip inwards, and the rate of turn must be speeded up by easing the control column back and by applying more bottom rudder, the angle of bank remaining constant.

(iv) If the rate of turn is too fast for the angle of bank, the aeroplane will skid outwards, and the rate of turn must be decreased by easing the control column forward and/or by easing off the bottom rudder, the angle of bank remaining constant.

(v) If the bank is increased, the rate of turn must be increased, and *vice versa*, bank being held off all the time.

Coming out of a turn.

241. In the early stages of instruction a point on the horizon should be chosen upon which to bring out the nose. Plenty of opposite bank and opposite rudder must be applied together—the rudder, not only to stop the aeroplane turning but also to counteract the aileron drag. At the same time, the control column must be eased well forward, because the application of opposite rudder on a bank tends to make the nose rise. When the aeroplane is straight and level, the controls must be centralised, the nose being kept on the horizon.

A steep turn.

242. In a steep turn the controls should be used as follow :—

(i) Commence as for an ordinary wide turn, but the bank must be increased by firm application of the aileron control.

(ii) A little rudder should first be applied towards the direction of the turn, but as the bank increases the rudder must be adjusted to keep the nose on the horizon.

(iii) At the commencement of the turn the elevator should be used to keep the nose from falling, but as the bank increases the control column should be pulled further and further back to keep the aeroplane turning in the horizontal plane. (*See* fig. 70.)

Faults in turning.

243.—(i) *At the commencement of a turn :—*

(*a*) Application of the rudder before the aeroplane commences to bank, which results in the aeroplane skidding outwards. To remedy this, reduce the amount of rudder or increase the bank.

(*b*) Application of too much elevator, as a result of which the nose rises. If the control column be pulled

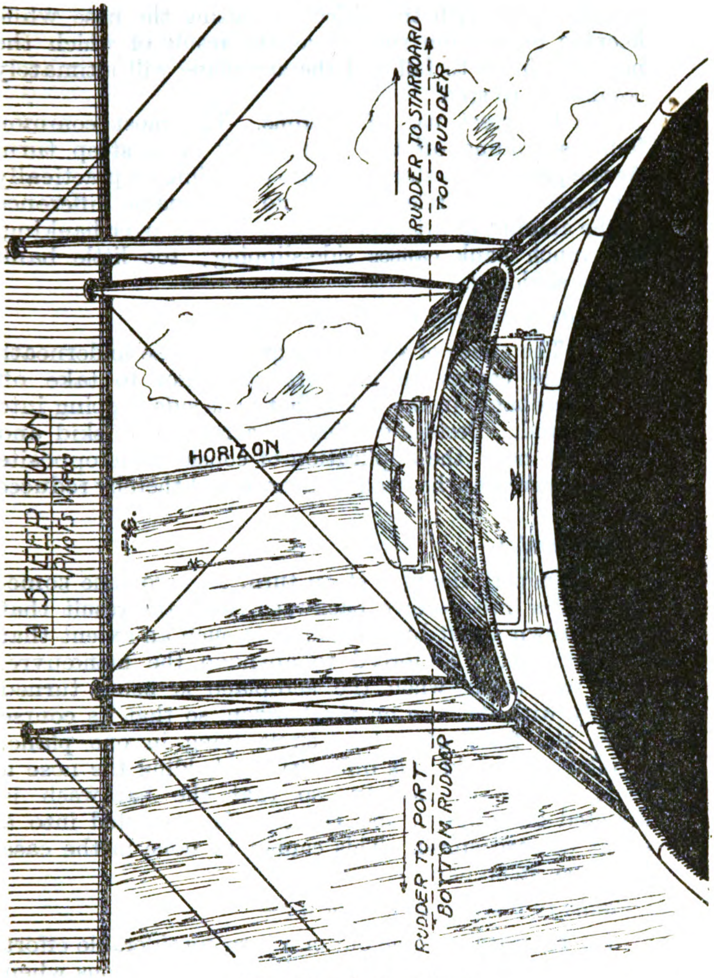

FIG. 70.—A steep turn.

back too soon, *i.e.*, when the aeroplane is only slightly banked, it will, if its speed is sufficient, complete a loop at an angle between the vertical and horizontal.

(ii) *When the turn is developed* :—

(*a*) Application of too much rudder; the nose of the aeroplane falls and the speed increases.

(*b*) Insufficient elevator; the aeroplane slips inwards. Remedy—more elevator or less bank.

(*c*) Too much elevator. A common mistake in a normal or steeply banked turn is to pull the control column back with the object of raising the nose while keeping on bottom rudder, as the result of which the nose continues to fall and the aeroplane will ultimately commence to spin.

(*d*) Incorrect use of ailerons. The most common fault is holding off too much bank on a steep turn. As the planes on a steep turn are travelling on practically the same sized circle, there is no appreciable difference in the amount of lift, and consequently no over-banking. Too much bank causes side-slipping; too little bank causes skidding.

(iii) *Faults in turning near the ground* :—

(*a*) The effect of seeing the ground close underneath sometimes causes an inexperienced pilot to take off too much bank, in the belief that he is side-slipping into the ground. Besides causing an aeroplane to skid and to lift its nose, the application of considerable opposite aileron increases the head resistance and thereby reduces speed.

(iv) *Backwash* :—

(*a*) In performing a steep turn, an aeroplane sometimes flies into its own backwash, with the result that it is thrown about by the eddies to such an extent that the pilot may be forced to abandon the manœuvre. This will occur when the aeroplane is being turned steeply with its nose on the horizon, so that its course takes the form of a true circle lying in one plane. A pilot can avoid this difficulty by holding the nose a little above the horizon, so that the backwash is directed downwards, and the turn is converted into a slight upward spiral. This cannot be done in the case of a very steep bank.

(v) *Faults in coming out of a turn* :—

(*a*) In order to come out of a turn considerable effort is required for sufficient application of the ailerons when taking off the bank. Full opposite aileron should be firmly applied, otherwise the aeroplane will be slow to respond. If top rudder is put on too soon, the aeroplane side-slips; if it is put on too late, it is slow in coming out of the turn and the pilot will not be facing the point of the horizon at which he was aiming. Failing to centralise the rudder at the correct time will cause the aeroplane to skid.

Gyroscopic action.

244. In turning, the pilot has to allow for gyroscopic action, the elementary principles of which are explained in paras. 47,

62, 63 and 64. On stationary-engined aeroplanes there is very little gyroscopic action set up by the rotation of the airscrew but on aeroplanes fitted with rotary engines gyroscopic action is an appreciable factor.

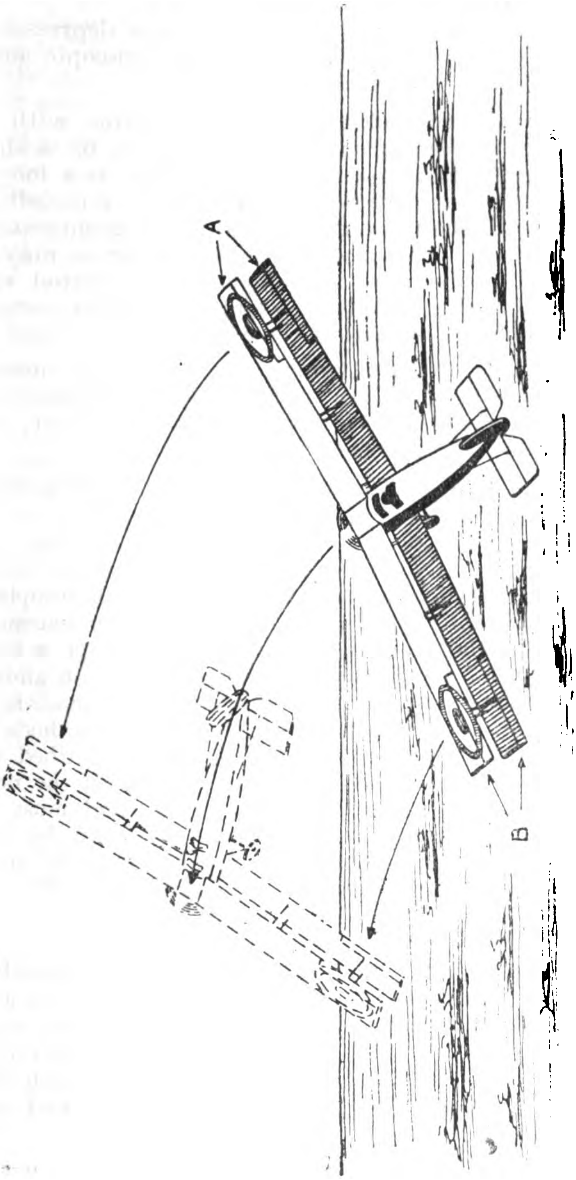

FIG. 71. On a banked turn the wing A has to travel further, and therefore faster, than wing B. Wing A consequently has more lift than wing B.

245. If a rotary-engined aeroplane of which the engine rotates clockwise, as viewed by the pilot, be turned to starboard, gyroscopic action not only resists the turn, but causes the nose to fall. Similarly, if the elevator be moved, gyroscopic effect tends to move the nose either to port or starboard according to whether the elevator is depressed or raised respectively. In flying, the effect of gyroscopic action is neutralised by the use of the controls.

246. The magnitude of gyroscopic effect varies with the rate of change of the alignment of the axis, *i.e.*, on a sharp turn it is greater than on a gentle turn. Thus, in a loop or sharp turn, gyroscopic effect is very noticeable, especially in aeroplanes with short fuselages, and needs counteracting with the controls. The effect of gyroscopic action may be demonstrated by means of an aeroplane model fitted with a gyroscopic fly wheel. A tractor aeroplane, with an engine rotating clockwise, as viewed by the pilot—

(i) tends to turn to starboard when its nose is raised, and to port when its nose is depressed.

(ii) tends to raise its nose on a turn to port, and to drop its nose on a turn to starboard.

The tendency is reversed with an engine rotating anti-clockwise, as viewed by the pilot.

Gliding turns.

247. Just as in a climbing turn the nose of an aeroplane has to be kept slightly lower than when climbing on a straight course, so in a gliding turn the nose must be kept a little lower than when gliding on a straight course. In a gliding turn the aeroplane does not tend to overbank, so bank need not be held off, as in a turn with engine. The methods of executing a gliding turn are similar to those described for a turn with engine. Before commencing the turn the nose must be just below the ordinary gliding line and must be maintained in that position throughout the turn by the application of a little bottom rudder; otherwise the nose will rise and the aeroplane lose speed and side-slip.

Faults in executing gliding turns.

248. Errors made in turning on the glide are somewhat similar to those made when turning with the engine on, and the remedies are identical. An aeroplane will tend to spin if during a steep turn flying speed is lost, or if rudder and elevator are used too coarsely. If this should happen the control column must at once be pushed forward and the rudder centralised.

Steep gliding turns.

249. In a correct gliding turn of over 45° the nose will appear to be above the gliding line; in fact, in an almost vertical turn, the upper side of the cowling will appear to be just below the horizon. This apparently high position of the nose is due to the side of the aeroplane being relatively higher above the pilot's eye than the cowling on the top of the engine over which he normally looks.

250. In executing steep turns on the glide inexperienced pilots may find it difficult to avoid seesawing the nose owing to the fact that, when rudder is applied, the aeroplane appears at first not to answer, and then rather quickly swings further than necessary. The reason for this sluggishness is the loss of sensitiveness of the rudder control, which is particularly apparent in a turn of this description and is due to the absence of slip-stream from the propeller.

Climbing turns.

251.—(i) The object of a climbing turn is to gain height whilst remaining as far as possible within gliding distance of the field from which the pilot is taking-off. This is necessary if the field is surrounded by bad country. It must be borne in mind that as the aeroplane is turning, and in so doing tending to lose speed, the angle of climb should not be so great as of an aeroplane flying horizontally, or a stall may result. The nose must therefore be kept below the normal angle for a straight climb. The angle of bank must not be steep and should be kept constant, as the steeper the angle of bank the less will be the climb.

(ii) There are two ways of going into a climbing turn :—

(a) *First method.*—If the aeroplane is climbing normally; ease the control column slightly forward to bring the nose below the normal climbing angle and commence a gentle turn in the usual way, keeping the nose in this position and maintaining the bank constant and rate of turn correct.

(b) *Second method.*—From the "flying level" position commence a gentle turn, ease the stick slightly back to bring the nose above the horizon but not up to the straight climbing position. Maintaining the turn and coming out of the turn is carried out in the usual manner, but it must be remembered that as the control column is slightly back, less rudder is needed than in an ordinary gentle turn.

SPINNING.

Spinning.

252. As explained in paras. 97 and 98, when an aeroplane is rotating about the direction of motion of its centre of gravity, it is said to be spinning. A spin is the natural result of an incorrect use of the controls causing the aeroplane in the first instance to stall. Most aeroplanes will spin if the control column is held back and full rudder applied, *i.e.*, if stalled, but an aeroplane can be forced into a spin when not stalled. Similarly, all aeroplanes will stop spinning if the control column is eased forward to central and the rudder centralised, the resulting manœuvre being a steep dive from which the aeroplane can be brought to gliding or flying position by gentle use of the elevator in the usual way. It is essential that in the initial stages of their flying instruction pupils should be taught rapidly to recognise a spin and recover from it in the least possible time; they should therefore be taught how to spin, in order to accustom them to the motion and to the rapid loss of height. Spinning must not be continued below 2,000 feet.

253.—(i) To demonstrate a spin commence an ordinary turn and keep on the bank until it is steep; then gently ease the control column back and apply full rudder in the direction of the turn, at the same time closing the throttle. The aeroplane will then spin. The speed of the spin is controlled chiefly by the amount the control column is held back, *i.e.*, the more the control column is held back, the faster will be the spin.

(ii) To come out of the spin, the control column must be eased forward to central, the rudder centralised, and the aeroplane brought out of the resultant dive as explained above. In some aeroplanes it is necessary to put the control column considerably forward of neutral; but in all types the control must not be applied too strongly in the opposite direction when correcting a spin because the aeroplane may spin in the opposite direction.

(iii) It is possible for some types of aircraft to get into a spin upside down. The most usual cause is an imperfect loop. It should be explained, but not demonstrated, to pupils that the method of recovery from an inverted spin is by easing the control column back and not forward as in the ordinary spin.

SIDE-SLIPPING.

254. Unintentional side-slipping is due to faulty flying and must be checked; but a side-slip properly executed is a most valuable method of losing height rapidly, without gaining either forward speed or distance, and if necessary

without changing direction. It is seen that this manœuvre is used when approaching to land, and it must be taught while doing so.

255. If it is required to side-slip to the left from the gliding position, put on left bank and a little left rudder to counteract the aileron drag. The aeroplane begins to slip to the left, and keel surface being affected by the resultant side wind, causes the aeroplane to turn to the left, which must be counteracted by application of top (right) rudder. The nose rises and should be kept a little higher than in an ordinary glide; to do this the control column will be eased back very slightly.

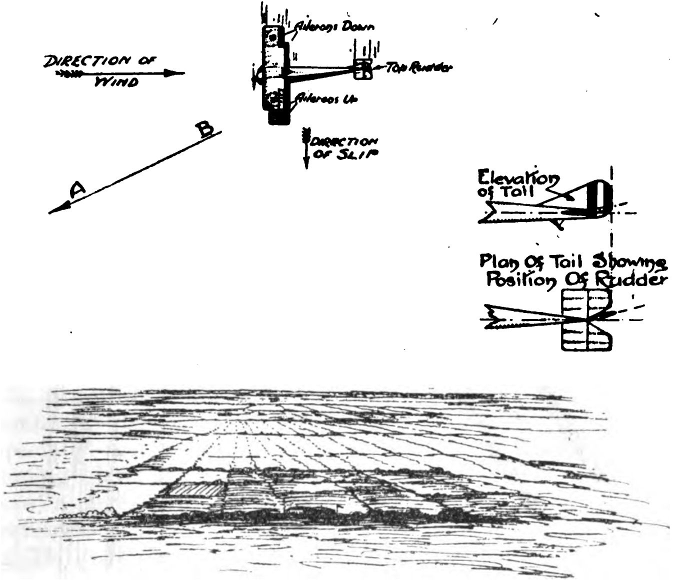

Fig. 72.—Side-Slipping. A-B is the resultant flight path. Illustration shows "top rudder."

256. In an approach to land, the side-slip should always be into or across wind but never down wind, as the down-wind drift over the ground is apt to upset the pilot's judgment. If the side-slip is done actually into the wind (*i.e.*, with nose across-wind) the method of recovery will be to convert the side-slip into a turn into wind before landing. This is done by holding on the bank, applying bottom rudder and centralising the controls when the normal glide is reached and the aeroplane is up-wind; but owing to the application of bottom rudder, the speed will tend to increase; this tendency must be counteracted by use of the elevator as necessary.

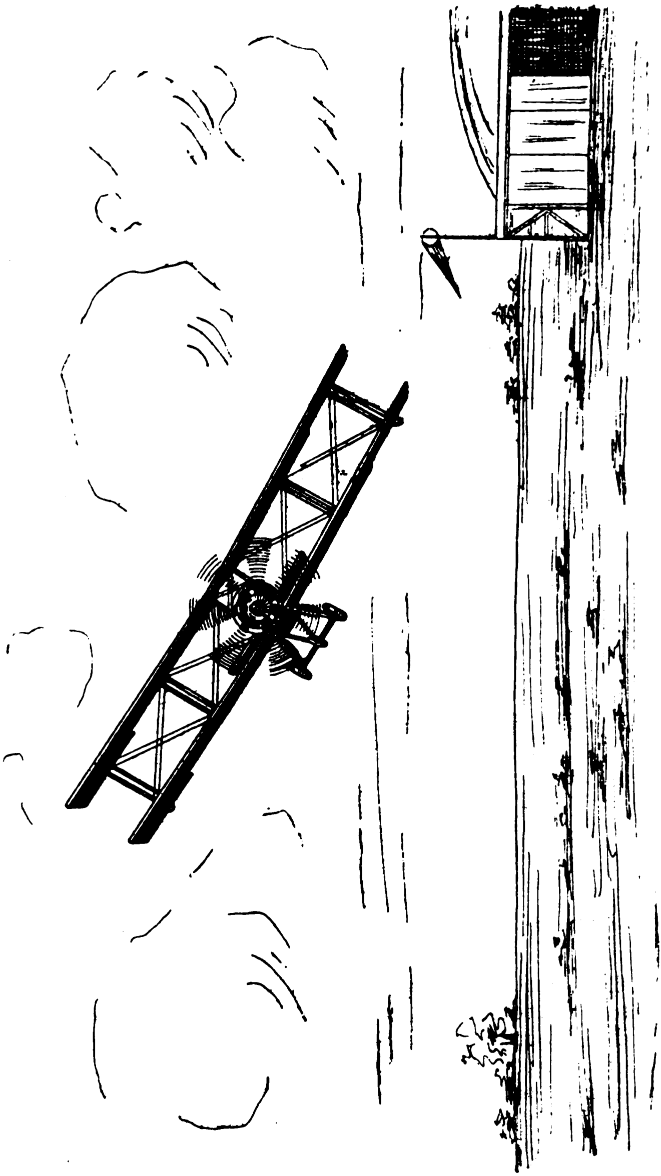

FIG. 73.—Side-slipping.

257. If the side-slip is done across-wind, *i.e.*, with the nose into the wind, the aeroplane on recovery, will be gliding into the wind. To effect recovery in this case, ease on opposite bank and a little more top rudder to counteract the

aileron drag, easing the control column forward to overcome the tendency for the nose to rise owing to the application of more top rudder, and when the aeroplane reaches the normal gliding position centralise the controls and land. (*See* figs. 72 and 73.)

TAKING-OFF AND LANDING DOWN AND ACROSS-WIND.

Taking-off across-wind.

258.—(i) *Effect of drift when taxying.*—When an aeroplane is taxying across-wind, the force of the wind exerts pressure on the fin surface, and the aeroplane is only maintained on a straight course by the friction of the wheels on the ground. As soon as the wheels are relieved of some of the weight, drifting commences. Tyres may be torn off and the under-carriage may break under a stress that it is not designed to withstand.

(ii) *Counteracting drift.*—In taking off across wind the pilot should fix an object ahead by which he intends to keep on a straight course; the engine should be opened full out as quickly as possible, and the tail brought into flying position by pushing the control column forward, at the same time the control column should be held right over to the side, which will cause the aeroplane to bank towards the wind until the inward side-slip caused by the bank is sufficient to counteract the drift. Lateral control is gained very quickly, especially on light aeroplanes. While the aeroplane is running along the ground with one wing down the nose will have a tendency to swing into wind and this must be prevented by the application of opposite rudder. (*See* fig. 74.) As soon as flying speed is attained the bank may be developed into a turn into wind, and directly the aeroplane is brought into wind, climbing should be commenced. After practice in taking off across-wind the pilot will find that as soon as the wheels leave the ground a climbing turn into wind may be started.

(iii) *Heavy aeroplanes.*—Special care should be exercised in taking-off heavy aeroplanes across wind because they do not gather sufficient forward speed to render lateral control effective before the effect of drift becomes serious.

(iv) *Turning down-wind.*—If, when attempting to take-off across-wind the pilot finds that drift commences before lateral control is obtained, the aeroplane should be turned slightly down wind as soon as the drift becomes too pronounced. This will result in a tendency to skid into wind, which reduces the amount of drift.

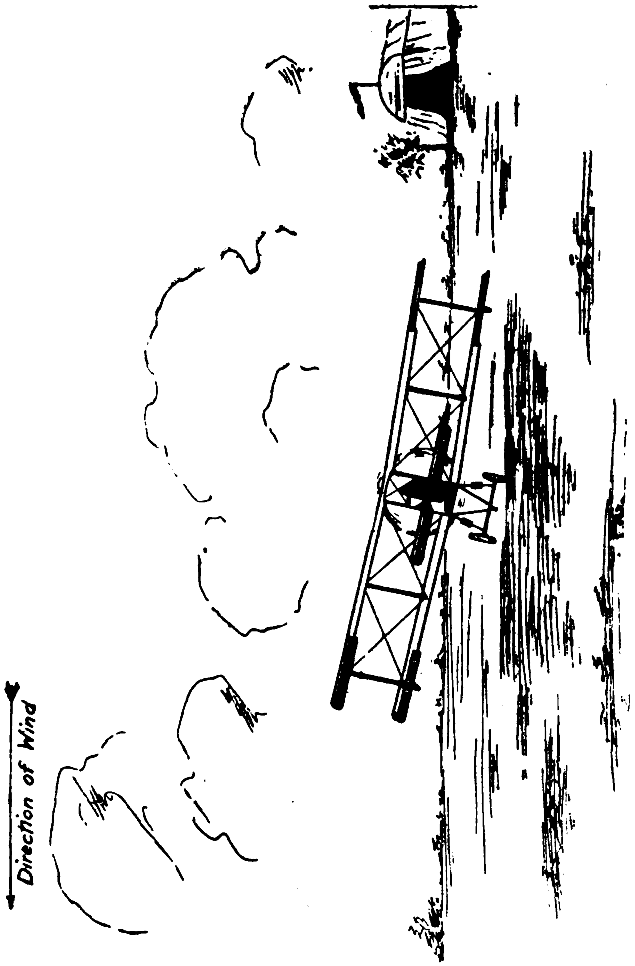

FIG. 74.—Taking off Across Wind.

Taking off down-wind.

259. Taking-off down wind should never be attempted except by experienced pilots for instructional purposes or in an emergency. Owing to the high ground speed required before an aeroplane attains flying speed, the rough or bumpy surface of the aerodrome is liable to cause the aeroplane to overturn or perhaps strain it. The path of climb in relation to the ground is comparatively gradual; consequently far more room is required if obstacles have to be cleared. (*See* fig. 68.) For example, for an aeroplane taking-off down a wind of 20 m.p.h., the usual taking-off speed of the aeroplane

being 40 m.p.h., the speed over the ground will be 20 + 40 = 60 m.p.h. as against 40 − 20 = 20 m.p.h. which is the speed required to take-off into a wind of the same strength. If a take-off down wind is unavoidable, a turn into wind should be commenced as soon as possible.

Landing across wind.

260.—(i) The principles of landing across wind are the same as those applied to taking-off across wind; that is,

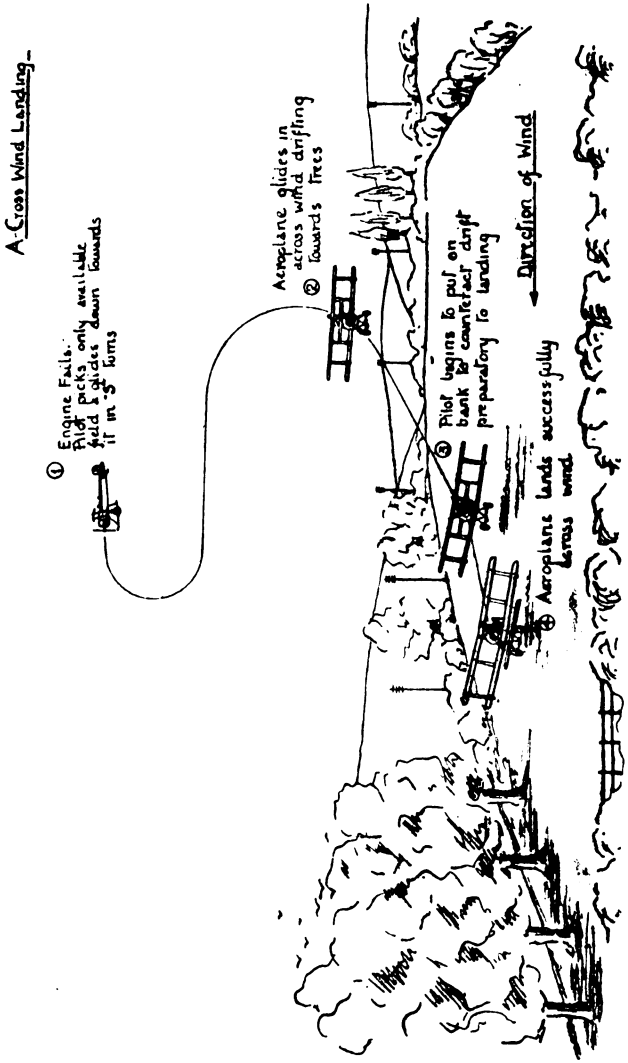
A Cross Wind Landing
① Engine Fails. Pilot picks only available field & glides down towards it in 'S' turns
② Aeroplane glides in across wind drifting towards trees
③ Pilot begins to put on bank to counteract drift preparatory to landing
Direction of Wind
④ Aeroplane lands successfully across wind

FIG. 75.—A Cross-wind Landing.

the drift is counteracted by side-slipping. Cross wind landings are useful on the following occasions :—

(*a*) When the landing ground is long and narrow in a direction at an angle to the wind, and therefore unsuitable for landing up wind.

(*b*) When a small landing ground is bounded on the leeward side by tall trees or other obstacles.

(*c*) In the event of a forced landing as described in para. 257.

(*d*) When there is a steep ridge and furrow at an angle to the wind. (*See* fig. 75.)

Furthermore, the knowledge of how to land across wind is of great value to the pilot, because he can then approach the landing ground from any of three directions.

(ii) To execute a cross wind landing the normal method of approach should be adopted until the aeroplane is within 50 or 60 feet from the ground. By this time drift will have become apparent, and the pilot must apply bank into wind, at the same time maintaining his direction by applying a little top rudder. The bank must be applied until drift disappears, and may even be held on until after the ground is touched, the landing being executed on one wheel. On nearing the ground care must be taken to reduce the bank sufficiently to avoid allowing the lower plane to touch the ground. (*See* fig. 75.) When on the ground the aeroplane should be turned down wind, if the strength of the wind necessitates, to prevent it from being blown over.

Landing down wind.

261. Landing down wind should never be attempted unless it is unavoidable. The ground speed of the aeroplane on touching the ground will be normal landing speed plus the speed of the wind, and if the pilot attempts to reduce this speed before touching the ground, the aeroplane will stall. The only occasion on which landing down-wind is expedient is when the ground slopes steeply down hill into wind ; in such circumstances it is better to land up hill and down-wind.

AEROBATICS.

General considerations.

262.—(i) Aerobatics, although not necessarily useful in themselves, are of extreme importance in the training of all pilots. They give a pilot confidence in his aeroplane and in himself and teach him how to control an aeroplane in any unforeseen position in which he may find himself at any time. In war, aerobatics form an essential part of tactics. Any manœuvre beyond ordinary normal flying turns and landings may be termed aerobatics. In all manœuvres the

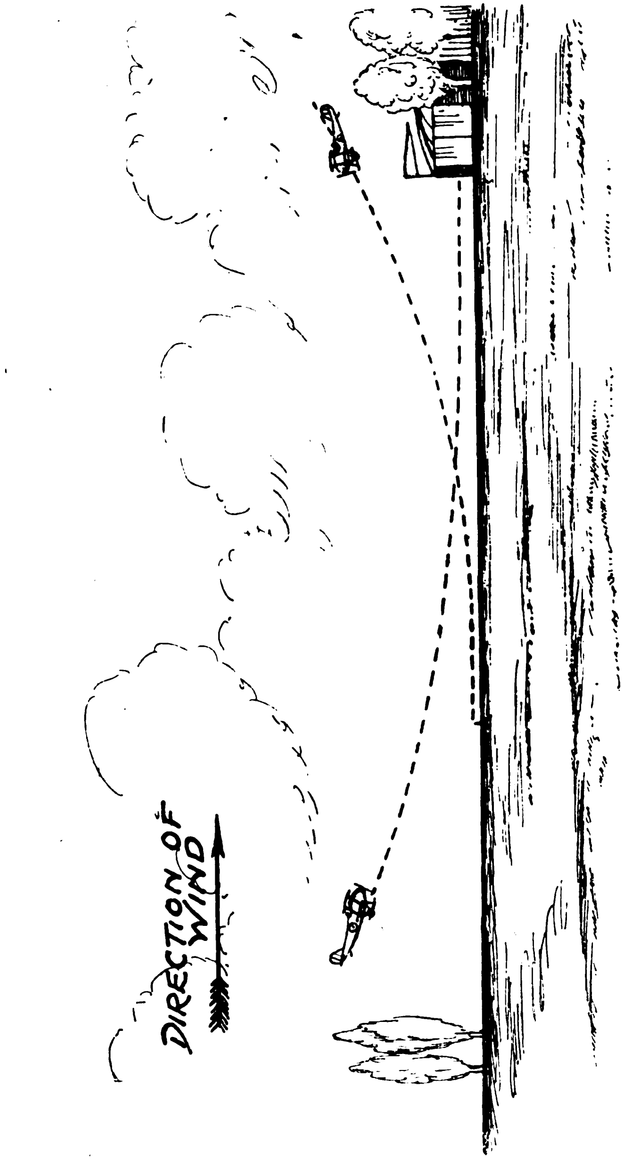

Fig. 76.—Landing. Effect of wind on path of descent.

highest standard must be aimed at, as a good manœuvre badly started or finished is entirely spoiled.

(ii) In addition to the ordinary training on an Avro, instruction must be given in looping and the half-roll. The full flick roll and the slow roll should not be taught, but the movements leading up to these manœuvres, *i.e.*, up to the time the aeroplane is upside down, can be shown very clearly, particularly when all movements are done slowly but deliberately.

Looping.

263. The aeroplane is made to travel in a vertical circle. The control column must be eased forwards slightly until a speed of approximately 10 m.p.h. in excess of full flying speed is attained. The control column must then be eased back gently, and any tendency of the aeroplane to swing checked by use of the rudder. If full rudder is not sufficient to keep the aeroplane straight, it indicates that the control column has been pulled too far back. As the speed drops so the control column may be eased further back, by which time the aeroplane will be upside down. When the nose of the aeroplane cuts the horizon on its downward path, the engine should be throttled back, and the aeroplane eased out of the resultant dive by use of the control column. (*See* figs. 77 and 78.)

"Flick" roll.

264. In a "flick" roll the aeroplane describes a turn about its longitudinal axis. The best speed for the roll is about 80–85 m.p.h., and the aeroplane will, owing to torque and slipstream, roll better in the direction of rotation of the airscrew as viewed from the pilot's seat. Having attained the necessary speed the engine must be throttled back to half throttle and the control column pulled back gently into one corner of the cockpit, at the same time rudder must be applied on the same side. It is of great importance that full rudder, aileron, and elevator should be used, otherwise the aeroplane may not "flick." The aeroplane will commence to bank, and when it has attained a bank of about 45° the "flick" will commence, and cause it to roll over quickly. The aeroplane should be checked from 90° to 45° before it reaches a level keel by the application of a little opposite control.

Half roll.

265. A "flick" roll must not be carried out on an Avro or large type of aeroplane owing to the excessive strain, but the roll may be started and checked as the aeroplane reaches the upside down position: the engine should then be shut

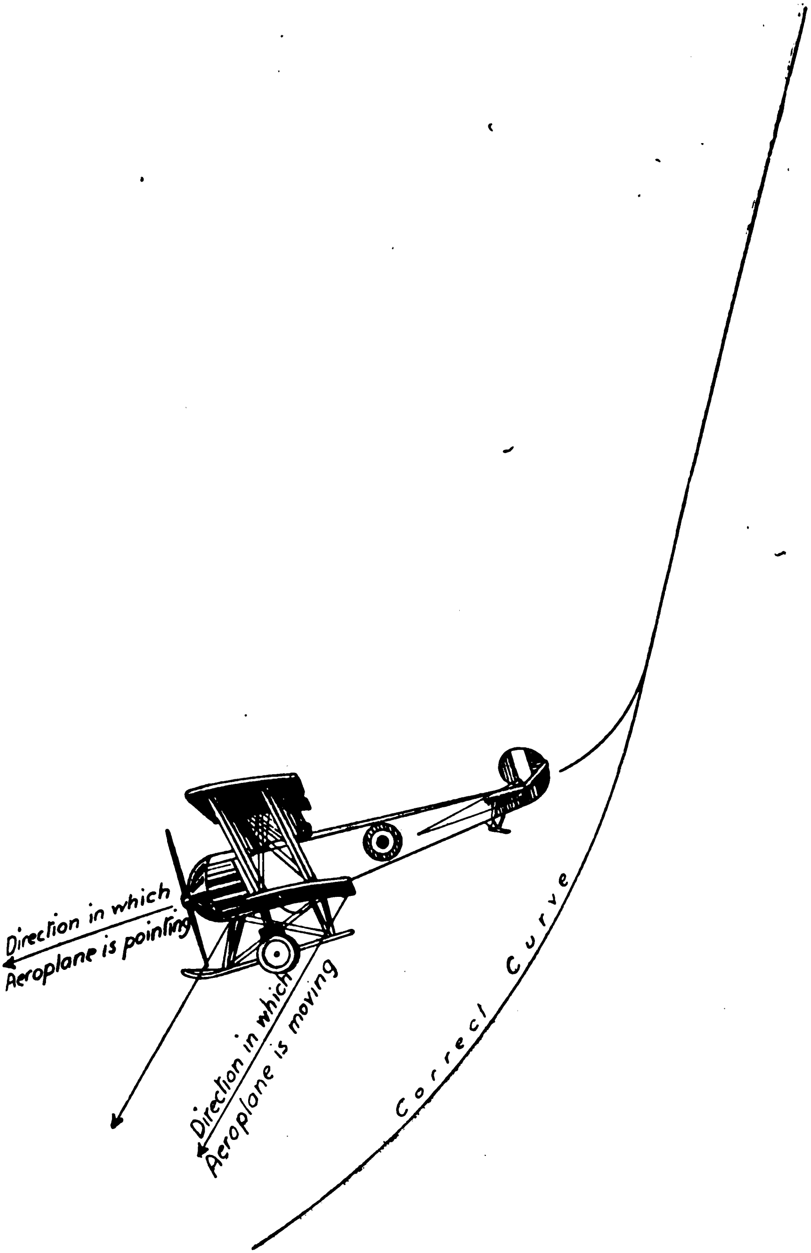

FIG. 77.—Looping. Incorrect use of control column.

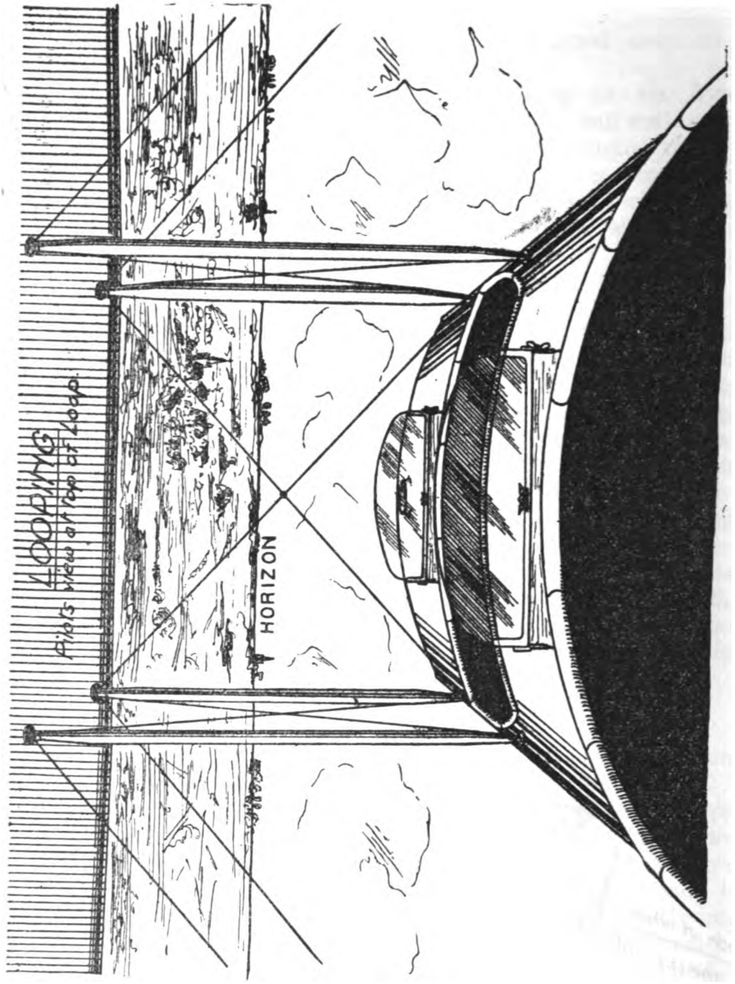
LOOPING
Pilot's view at top of Loop
HORIZON

FIG. 78.—*Looping.*

off, control column pulled back, and the aeroplane eased out of the resultant dive. This latter manœuvre is the same as the second half of a loop.

Slow roll.

266.—(i) The aeroplane is made to rotate about the axis of the fuselage. This manœuvre is best carried out on a small aeroplane, but can be done successfully on an Avro by an experienced pilot. The first half of a slow roll can be very well demonstrated on an Avro, which shows very clearly the compound movements of controls necessary for a successful performance of the slow roll. A speed of 75-80 m.p.h. should be attained on an Avro, and between 80-120 m.p.h. on a single-seater fighter, the nose of the aeroplane being then raised till the aeroplane is climbing. Next full bank should be applied and enough rudder to overcome aileron drag, but not enough to start the aeroplane turning. As bank increases the control column should be eased forward and enough top rudder put on to prevent the aeroplane turning and to keep the nose above the horizon. As the aeroplane rolls over on to its back the pilot's weight will be taken by the shoulder straps. The control column must be sufficiently well forward to hold the nose above the horizon, and the rudder will have been eased off to keep the aeroplane straight. Bank must still be held on as the aeroplane continues to roll off its back. The rudder must be used in the opposite order to that in commencing the slow roll, and the control column must be eased back and controls must be centralised when the aeroplane is, once again, level laterally.

(ii) To complete the first half of a slow roll, the engine should be shut off as soon as the aeroplane is level on its back, the rudder used to keep the aeroplane straight, and the control column eased well back; the aeroplane will then dive out, as in the second half of a loop. Owing to greater speed when upside down than when in a loop, more height must be allowed for recovery and the aeroplane must be eased gently out of the dive.

Rolling off the top of a loop.

267. Before attempting this manœuvre, a pilot should practise looping until he can keep up the speed of the aeroplane at top of the loop to 10 to 20 m.p.h. above stalling speed. Then, having attained the top of the loop with plenty of speed, as soon as the nose nears the horizon the control column must be pushed well forward and bank applied at the same time. Enough rudder (on the same side as the control column, *i.e.*, left stick and left rudder) must be used to keep the aeroplane straight. The controls must be centralised as the aeroplane comes back to an even keel, when it should be well above its path before entering the loop. Should the aeroplane be stalled as the nose cuts the horizon, speed can be gathered by allowing it to drop a little, the control column may then be pushed forward and the manœuvre completed. Considerable height should be gained even by an inexperienced pilot, and this manœuvre is most useful in a combat as a means of gaining height and changing direction at the same time. In a Snipe, owing to the excessive torque, it is only necessary to push the stick into the left front of the cockpit on the top of the loop; no movement of the rudder is necessary.

Falling leaf.

268. Pull the aeroplane into its lowest possible stalling glide by holding the control column well back, then use full rudder and aileron together. Immediately the aeroplane banks over and tries to spin, use hard opposite rudder and aileron to check it and to force it over the other way. If done at low altitudes care should be taken not to stop the engine.

Low flying.

269. Flying near the ground is often very necessary, especially in time of war. It will be noticed that when very near the ground there is a tendency for the pupil to hold off too much bank, thus making the aeroplane liable to stall at a time when there is no possibility of recovery. This fault depends mostly upon the direction in which the aeroplane is flying with regard to the wind. When an aeroplane is flying low, the air speed is very pronounced with relation to the ground.

(i) *Flying down wind.*—The ground speed will seem excessive, and may cause the pupil to stall in an effort to hold the nose up to reduce speed.

(ii) *Flying across wind.*—The drift is easily liable to upset the pupil's judgment in turning, especially if turning down wind, when the apparent increase in the aeroplane's speed may cause the pupil to raise the nose and so stall.

270. Much practice must be given in low flying to enable the pupil to become accustomed to the effect of the speed and the direction of the wind upon the air speed of the aeroplane in relation to the ground speed. A very careful look-out must be kept for obstacles, especially straight ahead, the most difficult direction in which to see. As much ground speed as possible, without overrunning the engine, must be maintained, so that in the event of a forced landing becoming necessary, the aeroplane may be turned with safety in any desired direction.

High flying.

271. Pupils should be encouraged to fly at high altitudes in order to get accustomed to the physical sensations of low air pressure, and the different "feel" of the aeroplane controls. They should not attempt great heights at first, but, in successive flights, go higher and higher, until the aeroplane reaches its approximate ceiling. After a certain amount of experience the feeling of strangeness resulting from reduction of pressure will pass off, although the brain is less alert under these conditions and the body more easily exhausted. If oxygen apparatus is provided, it should, of course, be used.

272. As the height increases the stalling speed increases and the maximum speed is reduced until, at the ceiling, they are coincident, but as the air-speed indicator underestimates in rarefied air, the reading indication of the stalling speed remains nearly the same. As the stalling speed increases the best climbing speed increases, and pilots must remember that the aeroplane cannot be climbed so steeply at a height as near the ground. The best climbing angle near ground level may be a position of stall at 15,000 feet.

273. While flying at a height, the pilot should make proper use of the altitude control of the engine (*see* para. 452). As individual engines differ in this respect, and the correct use of the altitude control makes a great difference, not only to the fuel consumption but to the life of the engine, their idiosyncrasies should be studied.

274. After flying at a height for any length of time, the pilot should, before landing, fly quite close to the ground for a few minutes, in order to recover his judgment, which is apt to be upset by high flying.

Cloud flying.

275. Correct flying in clouds demands considerable skill and concentration, and should not be attempted by an inexperienced pilot. In clouds the usual guides by which a pilot ascertains his position and altitude in relation to the earth are not available, and he has to rely only upon his instruments. Owing to the fact that the pilot feels no difference in sensation between flying straight and doing a correct turn, he cannot tell if he is flying straight or not, except by instruments. In any correct turn the pilot's weight presses normally on his seat, but in a steep turn his apparent weight is noticeably greater than normal.

276. To fly straight, the pilot must watch his compass continually, at the same time paying due regard to keeping the air speed correct and preventing side-slipping.

277. Climbing and gliding positions can only be judged by comparing the air speed with the engine revolutions. Great care must be taken to avoid stalling, as the recovery from a stall or spin when the pilot is surrounded by cloud or fog is very difficult, and may result in the loss of much height.

278. Cloud flying should only be practised to a very limited extent, if at all, at flying training schools, on account of the danger of collision in clouds if many aeroplanes are up at the same time. Fully qualified pilots should, however, practise as opportunity offers, taking care to ensure that the instruments are working correctly.

FORCED LANDINGS.

General considerations.

279. Before a pilot is permitted to leave the vicinity of the aerodrome on a cross-country flight he should be capable of landing without the assistance of the engine, in practically any type of country, without causing damage to the aeroplane. During flying training he should therefore be taught:—

(i) How to recognise the nature of the ground when flying over it, and how to select a landing ground.

(ii) How to estimate the strength and direction of the wind.

(iii) How to approach and land on a selected landing ground.

(iv) What action to take after landing.

(v) The care and maintenance of aeroplanes in the open.

280. Except when low flying is dictated by necessity, cross-country flights must be conducted at a minimum altitude of 2,000 ft. Provided that the ground can be seen, the greater the altitude of flight, the better for the successful execution of a forced landing; because, though it may be difficult to recognise a suitable landing ground from a great height, the time taken in gliding down can be utilised by the pilot in looking about him.

281. Whilst flying across country a pilot should always anticipate the possibility of a forced landing, and should therefore be conscious throughout the flight of the nature of the ground over which he is passing. Similarly, a pilot should frequently check the direction of the wind near the surface of the ground by taking the compass bearing of smoke, so that should a forced landing be rendered necessary he can at once turn into wind and select his landing ground. When the course lies across large areas of unsuitable landing country the normal altitude of the flight should, if possible, be increased.

282. To execute a forced landing successfully under adverse conditions requires skill and experience, which should be developed continuously throughout the pupil's flying instruction by means of constant practice in landing slowly on a previously selected mark on the aerodrome. Later practice should be extended to landings outside the aerodrome, in neighbouring fields and other suitable places, where unfamiliarity with the ground and local obstacles will tend not only to develop judgment and power of handling the aeroplane near the ground, but to teach the pupil to make up his mind rapidly in an emergency.

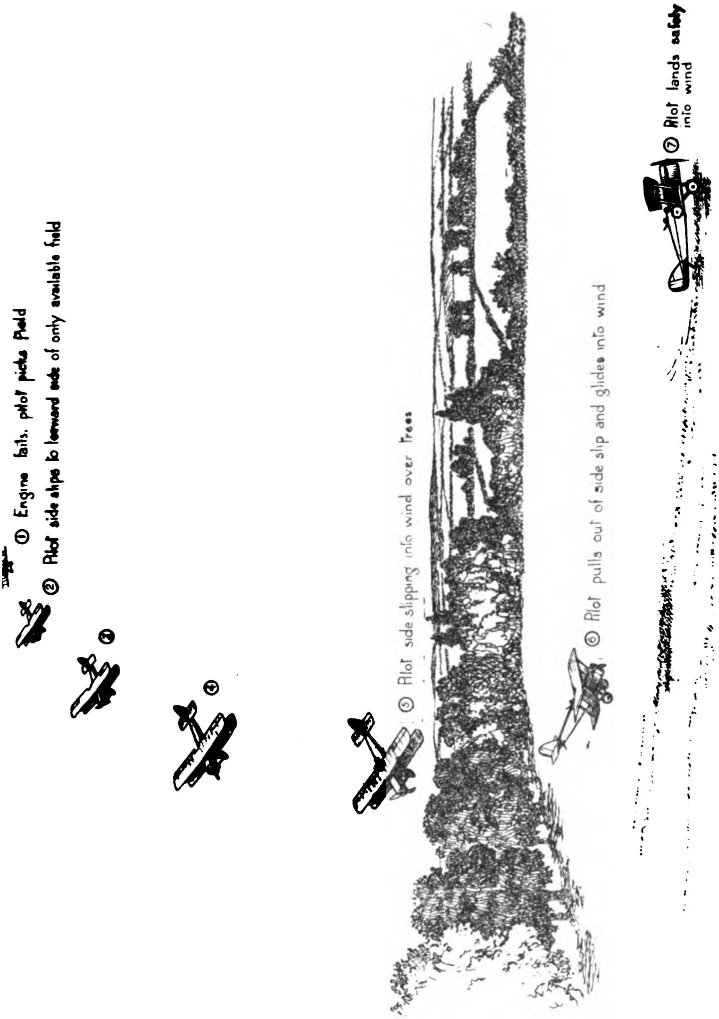
① Engine fails. pilot picks field
② Pilot side slips to leeward side of only available field
③
④
⑤ Pilot side slipping into wind over trees
⑥ Pilot pulls out of side slip and glides into wind
⑦ Pilot lands safely into wind

FIG. 79.—Forced landing over an obstacle in a strong wind.

Action to be taken when a forced landing becomes necessary.

283. A forced landing may be due to a variety of causes, the commonest of which is engine failure, and the action of the pilot will be influenced by the altitude at which he is flying at the time, the nature of the country over which he is passing, and the cause which renders the landing necessary. If a landing is rendered necessary by any reason other than engine failure, the pilot will usually have time to select a landing ground and land without difficulty.

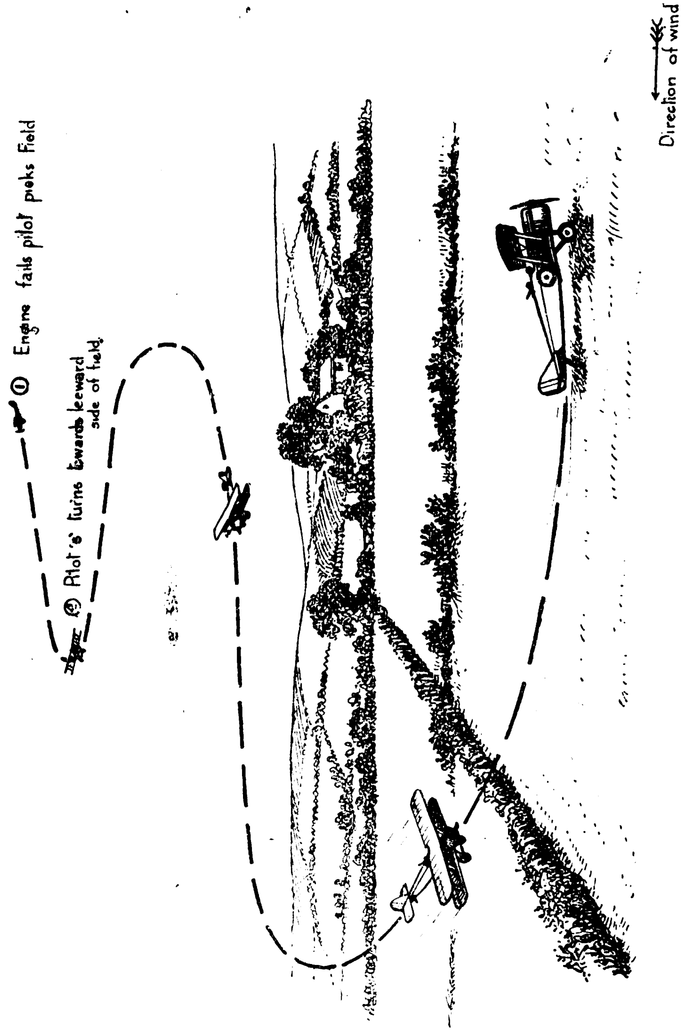
① Engine fails pilot picks Field
② Pilot's turns towards leeward side of field
Direction of wind

FIG. 80.—Executing a forced landing.

284. The ease with which a forced landing without engine can be effected is largely dependent on the altitude at which the failure occurs, and the most difficult situation is the one in which a pilot has just taken off and has not gained sufficient height to allow him freedom of manœuvre. There is one rule that should be impressed on all pilots, for its neglect causes more accidents than all other flying mistakes—*if engine failure occurs whilst taking-off, a pilot should never*

turn down wind, but must select a landing ground ahead, however unsuitable the country may seem.

285. The time available for selecting a landing ground varies according to the altitude at which a pilot is flying at the time. Thus, if engine failure takes place at an altitude of several thousand feet, the pilot, whilst gliding, may first devote his attention to locating the cause of the trouble. Petrol cock or throttle may have been closed accidentally, or a switch may have been knocked "off" inadvertently, and the pilot will have time to glance at these points before finally deciding to land.

286. It is generally advisable to turn off the petrol as soon as a forced landing has been decided upon, for to continue making use of a failing engine may interfere with judgment and is liable to aggravate the engine trouble. In any circumstances, an engine should be throttled back or switched off before actually landing, otherwise it may pick up temporarily at the last moment and thus upset the pilot's calculations.

287. If he is flying low at the time that a forced landing is rendered necessary the pilot will have to arrive at a decision instantly, and his choice will be limited to ground lying up-wind. During flying training a pilot should acquire the instinctive habit of putting the aeroplane into gliding position immediately engine failure occurs.

Selection of landing ground.

288. Once a pilot has made up his mind to land he must adhere to his decision, even if the engine suddenly picks up again just as he is nearing the ground. For if, after selecting and approaching a point to land on, the pilot suddenly changes his mind because the engine appears to recover, he may have complete failure a few moments later when flying low over unsuitable ground, with disastrous results.

289. The considerations that affect a pilot's decision in selecting a landing ground are various, but are dependent on his radius of action, *i.e.*, the distance that he can proceed before landing, either by gliding, by engine power, or by a combination of both. The chief requirements for a good landing ground are :—

(i) Firm, level surface and sufficient space in which to effect a landing up-wind.

(ii) Up-wind approach clear of obstacles such as trees, houses, telegraph wires, etc.

(iii) Proximity to road or track.

(iv) Clear "take-off."

290. A pilot may at first experience difficulty in ascertaining the "lie" of the country over which he is passing. With practice, however, he will be able to form a fairly accurate estimate of the presence of hills and valleys, being assisted by the appearance and shape of fields and woods, and by the position and extent of shadows. Heather, scrub, chalk, light-coloured grass fields and stone walls, usually denote high ground, whereas rich dark green vegetation in the absence of a stream generally indicates the presence of low or boggy ground. As the pilot descends to lower altitudes the formation of the ground is more easily recognised. The shape of fields and the general appearance of ground features will guide him in determining the contour of the neighbouring country. It is useful in estimating contours to remember that in arable land, the lines of the furrows will normally be up and down hill (for surface drainage) and not across a slope. Near to a town or to extensive farm buildings beware of wire fences, invisible except for the line of the posts, dividing large pasture fields.

Types of landing surface.

291. The ability to distinguish between the various types of surface seen when flying across country is only acquired by experience, and pilots should therefore frequently compare the appearance of different kinds of land when viewed from the air and from the ground. The appearance and suitability for landing purposes of cultivated districts vary according to the season of the year, but the pilot will be guided in his selection by knowledge of the nature and condition of crops prevalent in the district over which he is flying.

292. The chief types of surface likely to be met with can be recognised by the following characteristics :—

(i) *Grass* appears a dull uniform green or, in autumn, a brownish green colour. It may often be recognised by the presence of horses, cattle or sheep grazing in it.

(ii) *Stubble* appears buff-coloured in the early autumn, according to the time which has elapsed since the crop has been cut. In stubble regular rows can generally be seen. Stubble is one of the best surfaces for landing on.

(iii) *Growing crops.*—The colour of these vary according to the season, but are much brighter in spring and lighter in colour than either grass or stubble. They can be recognised by the regular appearance and by the spaces generally found between rows. Crops should be avoided, especially in the summer. In a strong wind high crops and long grass show ripples or waves as the wind passes through them.

(v) *Root crops* appear dark green from the air with regular rows. Root crops make a bad landing ground, but may be used as such in an emergency if an aeroplane is landed slowly and parallel to the rows or furrows of the crop; and should the velocity and direction of the wind allow.

(v) *Ploughed land* is more general in late autumn and winter, and has a rich brown or red colour which varies according to the soil of the district. Ploughed land makes bad landing ground except in very dry or frosty weather.

(vi) *Sand* appears very light yellow or almost white when dry, and varies greatly in its suitability as a landing ground. Dry shifting sand is generally too soft to make a landing ground, but sand that is moist and firm is very suitable. On a beach the sand a few yards from the water's edge is generally suitable.

(vii) *Water* may be used by an aeroplane to alight upon when there is no landing ground available. The pilot must pancake from a sufficient height to ensure alighting on the water with practically no forward speed and as near the shore as possible.

(viii) *Snow* is very uncertain, and possesses a disadvantage of concealing the surface and of rendering obstacles almost invisible. The pilot should scan the surface for shadows which may indicate an obstacle or depression in the ground, and should endeavour to execute a very slow landing.

Obstacles.

293. Obstacles are difficult to see at an altitude, therefore a pilot should carefully examine the ground while gliding down: (i) Inequalities in the ground surface may often be discovered by the shadows they cast. (ii) The lowest part of a field can sometimes be recognised by the presence of a stream or a pond. (iii) Roads and railways are often lined by telegraph wires, and, as these are invisible at an altitude, sufficient height should be allowed to ensure the aeroplane passing over them. The presence of telegraph wires may often be recognised by the poles that carry them. (iv) Obstacles on the leeward side of a landing ground over which the pilot has to pass before landing necessitate a much longer ground, while obstacles to windward possess the disadvantage that the aeroplane will have to pass over them while taking-off. A skilful pilot can often avoid obstacles such as high trees by side-slipping or by landing and taking-off across-wind,

294. When selecting a landing ground the pilot should bear in mind that it is preferable to land over an obstacle, such as a wood or a town, and have clear space to windward for taking-off, than to select a field which is easy to get into but which will be very difficult to fly out of. A small field with clear approaches to leeward and windward is preferable to a large ground encumbered by obstacles.

295. To avoid colliding with an obstacle which is suddenly discovered straight ahead when a pilot is attempting to land, bank and rudder should be applied simultaneously and then, as the inner wheel touches the ground, opposite bank. This method should only be applied in an emergency. The most difficult obstacles to avoid are those that are not readily distinguishable from above. The commonest of these are wire fences and telegraph wires, which can only be recognised from an altitude by their posts, or, as regards wire fences, by the regular shape of the grassland or crop. Ditches can generally be seen and avoided, and a pilot can sometimes jump a ditch by pulling back the control column, even when the wheels are on the ground.

Executing a forced landing.

296. Although, if engine failure occurs whilst an aeroplane is climbing off the ground, the pilot's choice of landing ground is limited by the fact that he must not turn down-wind, he may select a landing ground on either bow and turn slightly to port or starboard. Any superfluous height can then be lost by side-slipping, thereby enabling the pilot to manœuvre into landing position without losing sight of the selected spot. The methods employed in approaching a landing ground, and the manœuvre of landing, are set out in para. 357, but though the principles laid down are generally applicable to forced landings, the actual manner of landing must necessarily be modified to suit local conditions, especially when a pilot is forced by engine trouble to come down in unsuitable country.

297. When once a pilot has selected his landing ground, nothing but the discovery of unavoidable obstacles on it should cause him to change his mind and attempt to land on another apparently more suitable spot. The ground selected for a forced landing will seldom meet all requirements. The surface may be good but the wind be blowing across it, or, it may lie up-wind but have a rough surface. If the pilot changes his mind at the last moment because he prefers what he considers to be a better piece of ground to land upon, he interferes with his pre-calculated approach and may in the end fail to reach either.

298. A pilot should guard against the error of undershooting a landing ground, and though height be lost to leeward, he should always be in a position to turn into wind with sufficient height to spare. It is always better to "overshoot" than to "undershoot" a landing ground, and less damage is likely to result in the event of striking an obstacle. (*See* figs. 79 and 80.)

299. When local conditions are unsuitable for normal landing, the aeroplane may have to be "pancaked" from sufficient height to reduce forward movement to a minimum on reaching the ground. If the landing ground has been heavily ploughed, bears growing crops, or is very broken, the wheels will receive a sudden check and tend to turn the aeroplane over. This may be avoided by flattening the glide a few feet higher than normally and manipulating the landing so that the tail-skid touches the ground before the wheels.

Taking-off after forced landing.

300. Before attempting to start the engine, the pilot must—

(i) Inspect the ground over which his aeroplane will travel;

(ii) Make a note of the direction and strength of the wind; and

(iii) By a short survey of the surrounding obstacles decide which is the most advantageous way for the aeroplane to take-off.

If the choice lies between a take-off up a steep hill and up-wind or down a hill and down-wind the latter alternative is generally preferable.

301. If the pilot finds himself in a small field surrounded by high obstacles, he should consider the possibility of removing some of the load, passengers, guns, bombs, &c., and transporting it to a larger field. It might be possible to fly the lightened aeroplane from the small to the large field and there load up again. Much work might be saved, as the aeroplane would not have to be dismantled.

Instructions to troops in the event of forced landings.

302. The War Office have issued instructions as regards the action to be taken by troops in the event of forced landings by aeroplanes.

INVERTED FLYING.

General remarks.

303. One would naturally expect, and it is borne out by experiment, that an aeroplane which is comparatively unstable

in normal flight will fly in an inverted position more readily than one which is more stable. The only aeroplane at present in use in the service which is really suitable for inverted flying is the Snipe, and most of the following remarks apply particularly to this type. Inverted flying has, however, been successfully carried out in Camel, S.E.5.A (both now obsolete), Siskin and Grebe aeroplanes, but the last two named are too stable to fly in an inverted position very readily.

304. Although, subject to certain special peculiarities, there is little difficulty in controlling an aeroplane while inverted, the pilot's sensation of hanging head downwards on the safety straps is at first an unpleasant one, and tends to confuse his senses, making it difficult for him to correct the results of atmospheric disturbances and errors of flying, and to use the controls as quickly and delicately as is desirable. To control an aeroplane effectively, the pilot must, as it were, sympathise with its flying qualities. If he treats it as something foreign to himself he tends to make a purely mechanical use of the controls not in harmony with the flying qualities. If, however, he studies its motion closely, he will find that its properties of balance, its stability characteristics, or the gyroscopic effect of the engine, may be employed to relieve his control surfaces of a considerable part of their work, and in so doing allow them a margin of effectiveness to be acquired in no other way. More especially in an unstable aeroplane, a number of the pilot's control movements are made to damp various kinds of motion which, although excited by the use of the controls, are yet the result of the aeroplane's natural propensities. This feature of control is important in inverted flying where, as a whole, the controls are less effective, and a given manœuvre may depend entirely for its success on utilising them to the best advantage. Bearing this in mind, the pilot will realise that if, with his controls, he excites a motion which the qualities of the aeroplane are such as to stimulate, the longer he allows the angular velocity of the aeroplane to increase, the more difficult his task of damping the motion will become, so much so that he may be compelled to abandon his original manœuvre and temporarily allow the aeroplane to take its course.

305. In order to make use of the above considerations, it is necessary for the pilot to have some point or points of reference. Normally he refers all the movements of an aeroplane to the ground, and he should so accustom himself to the sensation of inverted flight that he can still find the aeroplane's position with reference to the ground, and to some extent use his instruments.

Methods of attaining the inverted position.

306. Before attempting inverted flying, the pilot should be quite familiar with the ordinary manœuvres of looping, rolling and rolling off the top of a loop. He should practise loops and by watching the air speed indicator during the loop he will see that in an ordinary loop the speed at the top is often as low as 40 or 50 m.p.h., *i.e.*, well below the stalling speed of the aeroplane. This is to be avoided if the aeroplane is to maintain an inverted position, as it might lead to an inverted stall, with the possibility of an inverted spin.

307. If a pilot chooses to manœuvre into an inverted position by means of a half loop, he must have sufficient speed at the commencement. All aeroplanes stall at a higher speed in inverted than in normal flight, and for a Snipe the initial speed should be at least 120 m.p.h. On reaching the top of the loop the pilot pushes the stick forward to keep the centre section on a level with the horizon and centralises the rudder, left rudder having been applied during the loop to overcome gyroscopic action, which ceases again when the aeroplane commences to fly inverted. If the speed drops below about 65 m.p.h. the pilot should continue the loop and try again. While flying invertedly the controls have exactly the same effect with respect to the planes of reference (axes) of the aeroplane, as when flying normally, and if the pilot keeps this in mind he should find no difficulty in using them correctly.

308. The second method of attaining the inverted position is that of the half-roll. This may be either the slow half-roll carried out mainly with the ailerons, or the " flick " half-roll produced by operating the rudder and elevator. In the first case the pilot should select a point on the horizon and keep it straight ahead, the speed being about 80 to 100 m.p.h.

(i) Should the roll be to the left the stick is pushed hard over to the left, and a little left rudder applied to overcome aileron drag. As the aeroplane banks the control column is pushed slightly forward and the left rudder eased off. After the aeroplane has passed the vertical bank the control column will have to be held considerably forward and a little right rudder applied to keep the nose up. When the aeroplane is on an even keel upside down, controls are centralised.

(ii) If the pilot elects to " half-roll " quickly, he carries out the ordinary movements for a quick roll, and just before the aeroplane reaches an inverted position he should take off aileron, push the stick forward, and at the same time centralise the rudder or put on a little opposite rudder

After a little practice neither method will present any difficulty.

Maintaining inverted flight.

309. As explained in para. 307, the controls work in the same way as in normal flight, but it must always be remembered that, whereas in normal flight speed is increased by pushing the control column forward, in inverted flight it is increased by pulling the control column back. The pilot must bear in mind that the stalling speed is higher than in normal flight and the control is somewhat less effective. A convenient speed for inverted flying is 80 to 90 m.p.h. Horizontal inverted flying may be carried out at this speed as long as the engine continues to run. On the "Snipe" this will be for about 30-60 seconds, and if the engine be kept full on, the aeroplane may be made to climb. When the engine stops the control column must be pulled back or a stall will result.

310. The movements made in normal flight for turning must be reversed except for the rudder, *i.e.*, to turn to the left, right "stick" and left rudder must be applied (as seen by the pilot) and the "stick" pushed forward to keep the nose down and to help the turn. This will seem strange at first but will become easier with practice. It is advisable to have the tail-plane adjustment set forward, *i.e.*, nose-heavy, to secure greater stability when inverted.

Resuming normal flight.

311. There are two methods of resuming normal flight, as for attaining the inverted position, *i.e.*, by means of the second half of a loop, or a half-roll. The first method involves the loss of some height, approximately, a minimum of 500 feet, the second method practically no loss of height.

312. To resume normal flight by means of the second half of a loop, the pilot pulls the control column gently towards him, and the aeroplane will commence an over-the-vertical dive, from which he can ease it round as in the end of a loop. During this manœuvre he must handle the aeroplane gently but firmly. If he is at all uncertain in pulling the control column back, the aeroplane will gain speed in the over-the-vertical dive with great rapidity, making it harder to ease round and flatten out into normal flight. On the other hand, if he pulls the column back too hard, it may come round with a jerk, and so subject the aeroplane to unnecessary stress. The pilot may find that at first the column comes back easily and then suddenly has a violent effect. It is necessary to feel for this carefully, and damp an over-violent elevator effect by easing the control column slightly forward again

A little practice is required to bring the aeroplane round in a smooth even curve without letting it acquire too much speed and so lose height unnecessarily.

313. A more graceful method of resuming normal flight is by means of a half-roll. Experience gained up to the present indicates that it is necessary to treat an unstable aeroplane differently from a more stable one, and that special care should be taken to harmonise the use of the controls with the natural characteristics of the aeroplane. The rudder and elevator appear to be the essential controls, while the ailerons, although they can certainly be made to help or spoil the manœuvre, are, in the same way as with spinning, of less importance.

314. On the more stable types, the best way to induce the half-roll is to put on rudder and push the control column right forward (on these types the pilot will have the control column well forward to maintain inverted flight) and put on aileron on the same side as the rudder. As long as the aeroplane is inverted, the pilot cannot afford to pull the control column back, as the self-righting tendency of the aeroplane will then be assisted by the elevator and the nose will drop immediately. With control column forward and full rudder the aeroplane should start to roll over. Then, as it comes over, the control column is brought back, the whole movement, allowing for the use of aileron, amounting to a kind of circular sweep.

315. On a highly unstable aeroplane, however, the pilot not only can afford to pull the control column back some distance, but is compelled to do so, because if he pushes it right forward when he has rudder on he may experience trouble which is dealt with in paragraph 322. On this type he can induce a good half-roll by putting on rudder, pulling back the control column gently and applying aileron on the same side. The aeroplane will then roll out, possibly rather violently, when he will have to damp the roll immediately after inducing it. Nothing looks so clumsy as to roll too far round, finish with one wing badly down and be compelled to pull it up again.

316. It will be seen that the pilot will have to exercise considerable judgment in the co-ordination of the controls, or the manœuvre will fail. He should soon find by experiment whether a particular aeroplane rolls out more cleanly with the control column back or forward, the proportion of rudder to elevator that it is best to give, the timing of the two control movements, and the way that the ailerons may be used to ease the motion of the aeroplane.

INVERTED SPINNING.

General remarks.

317. The characteristics of an inverted spin are in a general way similar to those of a normal spin. The inverted spin was first associated with loss of control following bad looping, or attempts at inverted flight by inexperienced pilots. Then, just as in the normal spin, pilots have found that the inverted spin can be practised as an intentional manœuvre; and, provided that the pilot knows what to do, he can recover from an inverted spin with almost the same precision as from a normal spin. As far as is known at present, a tendency towards inverted spinning is confined to unstable aeroplanes, such as the Sopwith Camel and Snipe, and only with them is it an easy matter to practise inverted spinning as an intentional manœuvre.

318. The conditions favourable to a normal spin are full rudder and control column back. Aileron is sometimes applied in the same way as the rudder and sometimes in the opposite direction, but it is essential that the control column should be pulled back towards the pilot. The conditions favourable to an inverted spin are full rudder and control column forward. Again, provided that the control column is forward, the aileron position seems to be one of the less necessary factors, but it has been found that aileron given in the opposite sense to the rudder produces a good inverted spin. The control movements, therefore, for inducing an inverted right-hand spin (left as viewed from the ground) would be, from the pilot's point of view, full right rudder and control column forward against the left-hand side of the dashboard.

Method of getting into an inverted spin.

319. If the pilot is gliding invertedly with engine off, he must push the control column forward until he is gliding at about 10 m.p.h. above stalling speed, approximately 75 m.p.h. He then pushes with his right foot, gently putting on full rudder, at the same time slowly easing the control column forward and to his left, until it is as far as it will go into the left-hand front corner of the cockpit. The aeroplane will then execute a flat turn to the right, and drop into the inverted spin. The pilot will tend to be thrown out of the seat, and it is especially necessary for him to be strapped in tightly. He can also steady himself by holding on to a seat bearer or anything convenient to his left hand. He should then find that the aeroplane is spinning evenly and smoothly on its back at something like 90 m.p.h. with its nose down about 45 degrees to the horizontal. The spin is on the whole a more comfortable and gentle spin than

the normal one. There is no evidence of " kick " sometimes experienced when spinning the right way up.

Method of recovering from an inverted spin.

320. When the pilot desires to recover from the spin, he must centralise the rudder and move the control column across from the left-hand corner to the centre of the dashboard and slightly towards him. He can then ease the aeroplane out of the resultant over-the-vertical dive by gently pulling the control column back, which will bring him round to normal flight. Apparently the aeroplane is more sensitive to coarse control movements than when recovering from a normal spin, and the pilot should use the controls gently, so as not to jerk the aeroplane. He should also try to damp its motion if it tends to jerk itself out of the inverted spin.

321.—(i) If he has got so far as executing an inverted spin, the pilot will naturally be in a position to experiment for himself, and will form his own opinion of the correct control movements to ensure the minimum stress on the aeroplane and the cleanest performance of the manœuvre. The inverted left-hand spin can be performed by putting on left rudder and pushing the control column into the front right-hand corner of the cockpit.

(ii) The recovery from an inverted spin involves nothing abnormal, but it should be emphasised that it generally takes a good deal more height than recovery from a normal spin, at least until the pilot has practised for some time. It is much easier to lose height rapidly in an over-the-vertical dive through mishandling of the controls than in any other condition of flight. It is wise therefore at first to ensure the control movements for recovery are not made at a height of less than 3,000 ft.

(iii) The pilot may possibly find that, due to hesitation or over-cautiousness in pulling the control column back to recover from an inverted spin, the aeroplane may stop rotating after centralisation of the rudder and actually start flying invertedly again, instead of coming round in an over-the-vertical dive. This need not worry him, in fact he may find that it is an alternative means of recovery. He could then half-roll out of the inverted position with practically no loss of height.

322.—(i) Now that the conditions favourable to the inverted spin have been discussed, it will be seen that the pilot, when attaining the inverted position or resuming normal flight, must be careful to avoid these conditions, with aeroplanes showing a natural tendency to spin invertedly, or else, instead of carrying out the manœuvre he wishes, he will spoil it by starting an inverted spin.

(ii) When half-rolling to an inverted position, the pilot starts by giving full rudder and pulling the control column back and to the same side; as the aeroplane passes over the vertical he must take off the rudder and push control column forward to ensure inverted flight. At this point the controls need careful handling; for if he pushes the control column forward too much when the aeroplane is approaching the inverted position, and still keeps rudder on, he has set up conditions favourable to an inverted spin. If this starts to develop, he can at once check it by pulling back the control column, but then the nose will drop and the manœuvre of attaining the inverted position be spoilt.

(iii) Similarly in resuming normal flight on unstable types by means of a half-roll, the pilot must be careful not to give too much rudder before pulling back the control column, or the same thing may happen. At the same time, if he pulls the control column back too much before giving rudder, he will fall into an over-the-vertical dive. He must compromise between the two extremes. The general idea is that if any tendency to an involuntary inverted spin is to be avoided the pilot must be careful not to use violent rudder when the control column is well forward. The more unstable the aeroplane the more need will there be to handle the controls carefully. On the other hand, with aeroplanes that are neutral or only just unstable he may experience no difficulty at all, and find that he can with impunity push the control column right forward when rudder is on. If he finds he can do this, he should use this elevator-rudder combination unhesitatingly, as it is a powerful weapon for the execution of rolls from the inverted position.

(iv) Finally, the pilot should always remember that the control movement (*i.e.*, easing the control column right forward) which ensures recovery from a normal spin is the very movement that induces and maintains the inverted spin and that, due to the persistence of habit, he may find at first that he has actual difficulty in making the mental effort to use the controls correctly. But as long as he knows how to diagnose faults in handling, he can always overcome them by practice.

CHAPTER IV.—THE FLYING INSTRUCTOR AND INSTRUCTION.

INTRODUCTORY REMARKS.

Principles of flying instruction.

323. Success in flying training depends mainly on the careful selection of suitable pupils combined with the employment of intelligent and highly trained instructors. A sound and logical sequence of flying instruction is also of great importance, though no system, however perfect, can be rigidly imposed, owing to the different temperaments of instructors and pupils.

324. It should be the aim of all instructors, whilst using this training manual as a basis, to adapt the system laid down therein to meet local requirements and to suit the individual characteristics of their pupils. It is a mistake to think that all pupils can be taught to fly by exactly similar methods; but the system of instruction should be standardised as far as possible, so as to permit continuity if instructors have to be changed before the pupil's tuition is completed.

325. A pupil must have complete confidence in the ability of his instructor; this is only possible if the instructor has complete confidence in himself. It is unlikely that an instructor will gain such self-confidence unless he is an experienced pilot and has been thoroughly trained as an instructor. An instructor cannot hope to be successful unless he is convinced that his pupil is physically capable of being trained into a good pilot. Should an instructor lose confidence in his pupil in this respect, he should immediately report the fact, with a view to cessation of the pupil's training or his transfer to another instructor. The changing of an instructor is often efficacious, since the temperament of the new instructor may be more suited to that of the pupil. A small percentage of pupils, however, will never make good pilots, owing to mental and physical disabilities which cannot at present be discovered by previous medical examination, and which may only become discernible when the pupil has actually received instruction in the air. It is important on the ground of economy to discover such pupils before time and money have been spent on their tuition; but this is often difficult, since the best pilots are sometimes very slow beginners. As a rule therefore it is difficult to decide, until a pupil has completed a considerable number of hours' flying, whether or not he will make an efficient pilot.

326. Of the time devoted to the training of a pilot, that spent in the air forms only a fraction. The amount of flying instruction which a pupil can daily absorb varies according to his physique and temperament. For most pupils in the early stages of instruction one hour each day is sufficient; but this period may be increased or decreased to suit the individual.

327. Many lessons may be taught on the ground and demonstrated in the air. Time spent in flying instruction is very expensive, and it is economical to provide only the minimum number of training aeroplanes and flying instructors; no lesson therefore should be taught in the air which could equally well be taught on the ground. A pupil's flying training must therefore be combined with a carefully worked-out course of ground training, so arranged that his skill as a pilot and his knowledge of airmanship progress evenly.

328. There are few undertakings in which physical fitness has so predominant an influence, both upon general efficiency and upon bodily safety, as it has in flying. It is generally recognised that a medically unfit pilot in charge of an aeroplane is a danger to himself and to those with him; but it is not always appreciated that, other things being equal, the more physically fit a pilot is the safer he is in the air. Officers commanding flying training stations therefore should have the advice of specially selected medical officers, who must live in close touch with the pilots of their stations and constantly advise their C.Os. concerning the health and nervous condition of the pilots. Apart from general efficiency, the question of actual risk is sufficient to justify the development of a cult of physical fitness amongst pilots, and is best attained and retained by clean and healthy living combined with plenty of exercise. Active games and sports are even better than physical training, as in addition to strengthening the muscles they train the limbs to respond quickly and accurately to the commands of the brain. C.Os. should therefore insist upon all their pilots taking part in sports and games, and should assume a personal interest in the condition of the playing grounds and in the organisation of the sports.

329. Good oral communication between instructor and pupil is essential, since some lessons can only be taught quickly in the air by demonstration with coincident explanation. Every flying instructor should have a sound knowledge of the elementary theory of flight and should be able to explain in simple language the theory of stalling, turning, spinning and other manœuvres. It is true that flying is mainly learned by imitation; but the lessons will be more

easily learned, and most lastingly impressed, if the pupil understands clearly the reason for his actions.

Instructor's influence on pupils.

330. The ease and quickness with which a pupil acquires the art of flying, and his utimate capabilities as a pilot, depend upon the keenness and ability of his instructor, quite as much as upon his own individual characteristics. It is therefore of the greatest importance that flying instructors should be chosen with special care, in order that the flying efficiency of the service should be maintained. An expert pilot does not necessarily make a good instructor, for he must not only be able to fly well himself, but be able to explain everything he does in a clear manner to his pupils. The effect of an instructor's influence cannot be over-estimated as it may make or mar the whole of a pilot's career.

Qualities required in an instructor

331.—(i) In order that one individual may be able to impart knowledge to another, three qualifications are essential. These are :—

(*a*) The possession of a complete and accurate knowledge of the subject to be taught, in all its branches.

(*b*) The ability to perform perfectly what has to be taught, and to do so automatically.

(*c*) The power of explaining the subject in such a way that it may be clearly understood by the individual undergoing instruction.

(ii) No one can be a really good pilot unless he has a whole-hearted enthusiasm for flying, and the same applies to an even greater extent to an instructor, who must not only be keen on flying itself, but on instructing; indeed this qualification is probably more important than any other, in that it induces a corresponding keenness in the pupil, and the will to fly being the most necessary element in the pilot's training will eventually result in his ability to fly.

(iii) A complete knowledge of the subject is required because one of the first essentials in flying training is for the pupil to have confidence in his instructor. This confidence will be shaken if the pupil finds that his instructor makes mistakes in flying or is unable to answer satisfactorily any questions that he may be asked. The theory of flight is, however, a wide and highly technical subject, and if asked a question the answer to which he does not know, the instructor must never give an evasive or inaccurate reply, but confess ignorance, and do his best to obtain accurate and authoritative information.

Ground training.

332. The instructor should take every opportunity to talk to his pupils on the ground upon the subject of flying, the aeroplane, and the engine. He must encourage them to ask and discuss questions. In this way he will be able to judge whether they are properly understanding what he is teaching them, and also to estimate their keenness. This knowledge will greatly assist him in deciding upon the lines of instruction to be followed with each pupil, in order to arrive at the desired result in the quickest way.

333. In the early days of aviation pupils were taught practical flying and theory of flight as two entirely separate subjects, with the result that they learned flying purely by imitation, without understanding the effect of controls, and they often failed to see the use of theoretical knowledge. The importance is now recognised of all pilots understanding the principles of flight and grasping the theoretical explanation of the various flying manœuvres.

334. It is not possible to give detailed theoretical instruction in the air, and instructors should be careful to make sure by conversation on the ground that their pupils understand every movement that has been dealt with in the air. Instructors should be familiar with the principles of flight laid down in Chapter I. and should lose no opportunity of improving their knowledge, so as to be able to answer clearly any questions that they are likely to be asked. Special attention should be paid to explaining the theoretical principles that affect the control of an aeroplane, particular care being taken to explain the theory of minimum flying speed and stalling, spinning, turning, and aerobatics. Pupils should be encouraged to overcome any natural distaste for mathematical symbols, and be given every opportunity of improving their knowledge of aeronautics.

Instruction in the air.

335. In flying instruction it must always be borne in mind that the knowledge of flying which the instructor is endeavouring to instil into his pupil must be absolutely accurate, and he must carry out all his own movements in the air accurately, as it is exceedingly difficult to correct bad habits once they have been formed. Moreover, accurate flying must be absolutely automatic, as the instructor will have to give his whole attention to his pupil and will have little time to spare for his controls. Instruction in the air is rendered more difficult by the following factors :—

(i) The noise of the engine, the strangeness of being in the air, and the necessity of communication by telephone, all tend to confuse the pupil until he has grown accustomed to these strange conditions, and to distract his attention from the instruction that he is receiving.

(ii) The instructor is unable to watch his pupil's face, and so ascertain by watching his expression whether he understands what is being taught, but has to rely on observation of his pupil's movements, upon his replies by telephone, and the manner in which his instructions are obeyed.

(iii) The instructor himself, until he has had considerable experience in instructing, may find it difficult to give explanations by telephone in the air. Instructors should always make a point of discussing the lesson with their pupils on landing, and must always make sure that they understand what has been taught. The instructor should impress his pupils with his love of flying and his absolute confidence in the air, and must be careful to avoid any display of excitement, even under the most trying conditions.

Use of telephones.

336. Communication during training in the air is by speaking tubes, commonly referred to as " 'phones," and it is of the greatest importance that these should be working properly. Ear-pieces should be fitted to the helmet exactly over the pupil's ears, and in such a way that no discomfort is caused. A helmet should fit fairly tightly so as to prevent wind passing between it and the face and so interfering with hearing. If satisfactory a helmet should be retained by a pupil throughout his flying training. Instructors should practise speaking into the mouthpiece which should be held close to the mouth and the speech should be slow and clear. If this is done it should only be necessary to raise the voice very slightly; shouting should be avoided, as this causes indistinctness and tends to fluster the pupil. It is convenient to fix the mouthpiece in a suitable position in the cockpit or hang it round the neck, in order to leave both hands free. The tone in which an instructor speaks to his pupil is of importance; a nervous, hesitating pupil should be encouraged and reassured, whereas a careless, slap-dash pupil should be checked.

Weather.

337. Instruction should take place in any weather in which the instructor himself can fly, as it greatly increases a pupil's confidence to feel himself capable of overcoming difficulties which he thought to be insurmountable. He

should realise that a pilot cannot consider himself capable of flying any type of aeroplane until he has handled it in bad weather.

Value of criticism.

338. A great deal of useful information may be gained by watching the flying of other pilots, and instructors should encourage pupils to make intelligent criticisms of each other's flying. After teaching in the air, an instructor should always go through the lesson again with his pupil on landing, and clear up any difficulties that may remain. When pupils are flying solo, they should invariably be watched by their instructors in order that any faults which may have developed in their flying may be corrected by a dual control lesson.

Flying accidents.

339. Apart from loss or injury to personnel and equipment, accidents undermine the confidence of pupils and must be avoided. The words "danger" and "nerves" must not form part of the instructor's vocabulary. Nothing that a pupil may do in the air is dangerous if he knows what he is doing and what the result will be.

340. Almost all accidents are caused by ignorance, and if, instead of telling a pupil that a manœuvre is dangerous, the instructor teaches him how to do it properly, he will possess the solution to any difficulty in which he may find himself. He should be made to understand that an aeroplane, being a mechanical contrivance, only does what the pilot causes it to do. A simple example is the turn. There are several ways of executing a turn, and the pupil should not only be taught the correct way, but must be shown every method of turning. He must be taught that a correct turn is just as safe near the ground as high up, and also that, if he elects to turn by kicking the rudder and holding off bank, he must allow air room to recover from the resulting nose-dive.

341.—(i) Any accident, no matter how trivial it may seem, should be closely inquired into. This may disclose a fault which, if it remain undetected, may be the cause of a serious accident at a later date.

(ii) Instructors should realise that accidents to their pupils reflect directly on their own abilities as instructors, and if the accident is the result of insufficient or incorrect instruction on a certain point, the instructor is to blame.

(iii) When an accident has occurred, various rumours circulate among pupils as to the cause of it. It is usually attributed by them to every conceivable failure except that of the pilot. As the majority of accidents are due to incorrect flying, it is advisable to lecture pupils publicly on the cause of the accident, as soon as it is established. Difficulties can only be present where there is doubt or ignorance as to their solution, and as soon as a pupil knows how the accident has occurred, it loses its depressing effect, and may drive home a valuable lesson.

Time given to dual control.

342. The number of hours' dual control that an instructor is capable of carrying out is dependent on a variety of factors which should be taken into account when allotting work and forming an estimate of results. As soon as a pilot loses his enthusiasm for flying he ceases to be of any value as an instructor. Officers in command of training units should therefore keep in close touch with the individual peculiarities and temperament of their instructors so that a rest may be granted when needed.

Confidence.

343. Most men can now be taught to fly, and many to fly well. It is obvious that some will always possess greater natural aptitude than others. These will naturally become finer pilots, but there is no reason why the ordinary standard of service flying should not be a high one. A really good pilot is born, not made, and although an instructor cannot make a good pilot out of an unsuitable pupil, he can prevent a moderate pupil from becoming merely a moderate pilot. The art of instructing lies in getting the best out of the available material. A good instructor will be able to decide in the early stages of instruction which of his pupils are likely to make good pilots and which will be useless, and the sooner the instruction of unsuitable pupils is abandoned, the better for both the instructor and pupil. If they are allowed to remain under instruction, a great deal of time and money will be wasted on them.

Instructor's style.

344. Flying, like riding, fencing, swimming and kindred sports, rests upon a basis of theory, but is acquired only after constant practice until the correct movements become instinctive. Thus it is necessary first of all to present a picture of the correct movements required for flight to a pupil's conscious mind, and then, by repeated practice, to cause this knowledge to become fixed in his subconscious mind; in other words, to accustom him to make the necessary movements automatically, so that the power of performing them becomes as much a part of his normal physical equipment as, for example, the power of walking. The instructor should take great care to avoid a parrot-like method of instructing, and must study his pupils, and adapt his methods

of instruction to their individuality; to enable him to do this, and to gain their confidence, his relations with them should be as friendly and informal as possible.

345. An instructor must, by getting to know his pupils, try to discover in what direction their interests lie, and vary the working of his instruction accordingly. For example, he may find one pupil to be of a mathematical turn of mind, and thus find no difficulties in grasping the mechanical principles of flight, whereas another may be an enthusiastic horseman, and the instructor may illustrate his lesson by drawing parallels between controlling an aeroplane and controlling a horse.

DUAL INSTRUCTION.

Preliminary dual instruction.

346. Before a pupil begins dual instruction he should be given a little passenger flying, if he has never been in the air before, to accustom him to the sensation of flying, so that he will be ready to derive benefit from his instruction in the air. The time necessary for this depends upon the pupil's temperament.

347. Dual should commence and continue in any weather in which the instructor himself can fly. The pupil must first be taken up into the calm air above the bumps, and the controls demonstrated. As soon as he understands them and appreciates their sensitiveness, he may be given full control. If the preliminary training on the ground has been efficient this should only occupy a few minutes. The pupil should then be taught to fly the aeroplane straight, and to land. From the very beginning, the instructor should never interfere with the controls when the pupil imagines himself to be in full control of the aeroplane, as this not only impairs his appreciation of the "feel" of the controls, but tends to make him lose confidence. The instructor should do all his criticism and correction of the pupil's faults by speaking through the telephone, and leave the pupil to correct his own mistakes, only taking control himself to make a fresh demonstration or to prevent a crash. In this way a pupil gains confidence in his own flying and ability to correct his mistakes.

348. From the start the pupil should try moving the controls with some vigour, in order to get used to their effect, and must never be afraid to use them freely. When he can fly straight, he should be shown the climbing and gliding angles, special attention being directed to stalling and the feel of the controls at different speeds. Taking-off and

landing should now be commenced. This requires fairly calm weather at first, but as much practice is necessary, time for further instruction may be found between later lessons, in more difficult weather. Pupils should be taken into the air as much as possible, even if the weather be unsuitable for landing practice.

349. No dual lesson should be too long. Half-an-hour is usually sufficient, and in lessons of landing especial care must be taken not to tire the pupil by too long a lesson. Most pilots have occasional bad flying days and if either the instructor or pupil is tired, or "off colour," it is useless to prolong the lesson, and it is better to come down at once.

350. When the pupil has acquired some idea of taking-off and landing, and only requires practice to make him perfect, he may be instructed in turning. It is best to start with turns of about 45° bank, because these are the easiest, and if more gentle turns be tried first the pupils may be afraid to bank steeply later on. Gliding turns should follow and then steep turns, with and without engine, after which spins should be demonstrated and the method of recovering explained. Throughout these later lessons instruction in landings should be continued, the pupil being told to do a few landings each time he goes up. When he can be relied upon to do a safe landing he should be given a little elementary instruction in forced landings, and then sent off solo.

Sequence of instruction.

351.—(i) The following sequence of instruction will be carried out when pupils are being trained *ab initio*. Pilots under training as flying instructors at the Central Flying School will be taught to instruct in accordance with this sequence. Items 10, 16 and 18 should not be taught to pupils who are undergoing flying instruction on aeroplanes of the single-engine or twin-engine bombing class. Pupils receiving flying instruction on these types of aeroplanes will be instructed in the manœuvres leading up to a spin and the subsequent method of recovery.

1. Taxying and handling of engine.
2. Demonstration of effect of controls (with and without engine).
3. Straight flying, level flying, climbing and stalling.
4. Gliding straight.
5. Taking off into wind.
6. Landing into wind and judging distance.
7. Turns up to 45°.
8. Gliding turns.
9. Turns over 45°, with and without engine.
10. Spinning.

11. Elementary instruction in forced landings.
12. Solo.
13. Climbing turns.
14. Side-slipping.
15. Taking-off and landing across wind.
16. Aerobatics.
17. Advanced instruction in forced landings.
18. Low flying (*i.e.*, correct turns at low altitudes).

(ii) The pupil will receive preliminary ground training in the theory of aeroplane control before he is taken into the air. It should not therefore be a matter of great difficulty to demonstrate to him the effect of the controls, and to teach him how to keep his aeroplane flying level and on a straight course.

(iii) It must be borne in mind by instructors that a pupil must have complete control of both aeroplane and engine from the very commencement of his training, and that the more proficient the pupil becomes in running his engine, the more confidence he will have in his own ability to handle the aeroplane. An instructor should never take the control of an aeroplane from a pupil except when demonstrating the particular manœuvre or when correcting a pupil if he gets into difficulties near the ground.

(iv) The pupil should always be placed in the pilot's seat from the very first lesson; he should be made to feel that he is really in control, and is not merely a passenger watching the controls being manipulated by the instructor.

(v) The pupil should run up the engine on the ground, and should always taxy the aeroplane out from the shed apron and in from the aerodrome from the very beginning of his instruction.

(vi) On commencing instruction in the air, the instructor should first demonstrate the effect of the controls, and instruct the pupil in flying straight, flying level, climbing and stalling (*i.e.*, 2 and 3 in the above sequence of instruction). Every time that sufficient altitude is reached in teaching the pupil 2 and 3, the instructor should shut off the engine and instruct the pupil in gliding straight, 4.

(vii) From this point in the instruction the pupil should always take the aeroplane off the ground, 5. The second lesson, therefore, will consist of 5, and in addition a repetition of 2, 3, and 4.

(viii) As soon as the pupil has become accustomed to the feel and appearance of an aeroplane being landed, he should begin to take control of the actual landing, 6.

(ix) Instruction in landing should be interspersed with instruction in turns up to 45° of bank, 7, and, when reasonable proficiency has been attained in these, in gliding turns, 8, and in turns of over 45°, 9.

(x) In landing practice, the instructor should always give the pupil a mark on which to land. The pupil should himself shut off the engine, judge his approach, and land as near to the given mark as possible.

(xi) The pupil should be instructed in spinning, 10, at the same time that he is being taught to execute turns of over 45° bank. In this way the instructor can demonstrate how a badly executed turn can develop into a spin.

(xii) Before the pupil is sent off solo, he should receive elementary instruction in the method of carrying out forced landings, 11. The instructor should shut off the engine, and inform the pupil that the engine has failed. Careful instruction should be given in the choice of fields and method of approach. The pupil must be warned that, in case of engine failure near the ground when taking-off, he must on no account turn back to the aerodrome.

(xiii) The pupil may then be sent off solo.

352. During the period of primary instruction the pupil should not be allowed to fly by the use of instruments. Later on in his instruction he may be permitted to do so for the purpose of learning cloud-flying. This does not apply to engine instruments which must be carefully watched from the beginning.

Solo flight.

353. The responsibility for deciding when a pupil is ready to fly solo must rest with his instructor and the chief flying instructor. If the dual control has been carried out efficiently, and the pupil has been in the pilot's seat throughout and realised that he has been constantly in complete control of the aeroplane, the first solo will not worry him much. It is generally advisable to send a pupil on his first solo immediately after a successful dual flight. The stage at which the pupil can be sent solo must be in accordance with the sequence laid down in para. 354 (ii) below. It is important that a pupil should complete his first solo flight as soon as he is considered ready to do so. Dual control must not be neglected because the pupil has gone solo; secondary dual must be carried out to ascertain whether the pupil is flying correctly and not developing any bad habits.

354.—(i) From the time he commences solo flying until he finishes his instruction as a service pilot, a pupil should never be allowed to go up and fly round the aerodrome without being given a definite manœuvre to practice.

(ii) A pupil must not be allowed to fly solo until :—

(*a*) He has mastered his turns.

(b) He can land reliably.

(c) He has a thorough grasp of the angles of glide and climb.

(d) He has been shown how to recover from a spin and a stall.

Advanced dual instruction.

355. When, after a few solo flights, the pupil begins to show confidence flying alone, and a thorough grasp of the lessons taught him, he must be given a further period of dual, between solo practice flights. The lessons taught in the first dual period should be repeated and any faults that may have developed be corrected. This repetition must include more landings. If the pupil at this stage shows reluctance to manœuvre freely, his confidence is at fault and the instructor must endeavour to discover the cause. The main object of this dual control period is to equip the pupil with the knowledge and skill to fly in all ordinary weather conditions. Steep turns in bumpy weather, landings and take-offs across wind, forced landings from low heights and choice of fields to land in, form part of this instruction, for all of which time should be found between solo flights. If a pupil gets into difficulties after being shown how to carry out any particular manœuvre, he should be allowed to test his own ideas of recovery, the instructor only coming to his rescue when necessary.

356. The importance of advanced dual control cannot be too strongly emphasised. The instructor should rigorously check any faults that may develop in the pupil's method of flying. He should also employ the time spent in advanced dual control in giving instruction in climbing turns, 13, side-slipping, 14, taking-off and landing across wind, 15, aerobatics, 16, advanced instruction in forced landings, 17, and correct turns at low altitudes, *i.e.*, low flying, 18.

357. The pupil should be taught to make a forced landing from low altitudes which naturally necessitates quickness of action, together with landings that involve the following manœuvres :—

(i) Slipping on a turn, *i.e.*, turning and losing height at the same time.

(ii) Methods of losing superfluous speed, *viz.*, skidding.

(iii) Slow side-slipping.

(iv) Landing on a turn.

(v) Steep gliding turns near the ground.

358. The chief object of low flying is to teach absolute accuracy especially in turns. The effect of losing height on

a turn carried out at an altitude is hardly appreciable, but if the same thing occurred near the ground it would be easily noticed. The pupil should be given a demonstration of the following:—

(i) Losing height on a turn.

(ii) The tendency to hold off too much bank near the ground.

(iii) The tendency to stall when turning down-wind, owing to the pilot's judgment being disturbed by the excessive ground speed of the aeroplane.

359. Aerobatics are a most important part of a pupil's training, and instruction in this subject must on no account be neglected. Ability to execute aerobatics produces confidence in a pupil more rapidly and effectually than many hours spent in straight flying and turns; it also stimulates the pupil's morale. The instructor should point out that accuracy in performing aerobatics is just as important as in more normal evolutions, and the pupil should realise that harsh use or misuse of controls often sets up severe stresses in the structure of the aeroplane.

360. A pupil should never be sent into the air with nothing more definite to do than to put in "flying time." Time so spent is time wasted. The instructor should always give a pupil a definite task to perform, and should, if he considers it advisable, watch the pupil carry out the allotted task. Flight commanders must from time to time test pupils who are being instructed by other instructors in their flight; they should also, if they consider it necessary, test any of their instructors. The following rules, which have already been explained, are summarised for the guidance of instructors:—

(i) The early stages of flying instruction are of great importance, and the pupil's first impressions will, in all probability, influence his whole career as a pilot. The instructor should therefore be as careful to avoid bad flying at the commencement of the pupil's instruction as in the final stages. A tendency has been apparent in the past amongst some instructors to test a new pupil's nerve during his first few flights as a passenger by throwing the aeroplane about in a series of sensational aerobatics. Nothing is more liable to disappoint and upset a pupil in the early stages of his flying experience. Until he displays some confidence in the air, and has accustomed himself to the unusual experience of flying, the instructor should, above all, avoid doing anything calculated to unsettle him.

(ii) The more experience that the pupil can be given of flying as a passenger before dual control is commenced, the more quickly will he digest his early lessons in flying. If time admits therefore every pupil should be given a preliminary course in the duties of an observer in the passenger's seat; the length of this course should be sufficient to accustom the pupil to flying under varying conditions of weather, to give him some knowledge of the use of his map and compass in the air, to stimulate his observation, and to teach him enough about the ground, as he sees it from the air, to enable him to discriminate between good and bad landing places.

(iii) If there is enough air space, a pupil should be allowed to correct his mistakes unassisted, and when in difficulties should be left to exhaust his ideas of recovery before the instructor intervenes. If intervention is necessary, the instructor should not only demonstrate the correct method of avoiding a recurrence of the faulty manœuvre, but should teach the pupil how to extricate himself from any difficulty into which he may fall through his original error.

(iv) Pupils should never be allowed to stand about on the shed apron doing nothing. There are endless opportunities for employment—airscrew swinging, engine running, impromptu lectures, flying criticism, rigging aeroplane inspection, examination of engine faults—and many others which will occur to an intelligent instructor.

361. No pilot should be permitted to undertake the instruction of pupils until he himself has been thoroughly taught the art of flying instruction by a competent and fully qualified officer. Apart from the fact that even the most experienced pilots are liable to develop faulty habits, of which they are themselves unaware until checked by a flying examiner, the work of a flying instructor is an art in itself; however expert a pilot may be, he is not fit to instruct until he has given to the subject the most thorough study and attention. He must learn to analyse the effect of every little movement of each control, both singly and in combination, and must be able to explain it to the pupil in clear English. He must never try and teach too much at a time, and must satisfy himself that the pupil has thoroughly mastered each successive step in his lesson before he proceeds to the next. He must learn to make himself heard on the telephone, to be patient, to keep his temper and, above all, to keep cool.

Subjects to be taught simultaneously with flying.

362. The following subjects can best be taught simultaneously with flying instruction; they provide suitable occupation for pupils while waiting for flying :—

(i) The care and maintenance of aeroplanes in hangars.

(ii) The inspection of aeroplanes and engines.

(iii) The moving of aeroplanes in and out of hangars and over bad ground.

(iv) Engine running and airscrew swinging.

(v) The care and maintenance of aeroplanes in the open.

363. An aero-engine is designed to give maximum power and reliability consistent with minimum weight. But its performance is largely dependent upon the treatment it receives both on the ground and in the air. Although the care, maintenance and repair of aero-engines requires the employment of highly skilled personnel, and is dealt with fully in separate handbooks, it is of the utmost importance for the purposes of flying training that a pilot should receive instruction in the following subjects :—

(i) Construction and working principles of engines used on service aircraft.

(ii) Treatment of an engine on the ground and in the air.

(iii) Examination of an engine before flight.

(iv) Recognition and diagnosis of faults by sound and other symptoms.

(v) Repair of minor faults.

364. In the initial stages of training, pupils should receive instruction on an engine fitted to a fixed fuselage. This fuselage should resemble the fuselage of a serviceable aeroplane complete with engine instruments; but it should be so fitted up that an instructor can affect the running of the engine and simulate the various faults to which an engine is liable. When teaching a pupil how to run an engine it is of great importance that an instructor should not only demonstrate the correct method of starting, running up and stopping it, but should explain in detail the necessity for each measure and the result of omitting it. Instructional engines mounted in ground fuselages should be the least perfectly adjusted of all engines on the station, so that when the pupil manipulates an engine in the air, he will find it easier to manage than those that he has run on the ground.

Instruction in flying aeroplanes of service type.

365. As soon as a pupil has become proficient in flying an Avro and has satisfied his instructor that he is capable of executing all the manœuvres described in Chapter IV, his training in flying an aeroplane of service type will commence. This should begin with ground instruction, and include the running of the engine, the use of the instruments and an explanation of the general characteristics of the aeroplane. A thorough course of dual control should follow.

366. Instruction in flying the service type should be, conducted precisely as laid down heretofore for the Avro, and the rules in para. 354 (ii) governing the flying standard to be attained before a pupil should be permitted to fly solo on an Avro, apply equally to the first solo on a service type, with the following exception. Pupils undergoing flying instruction on aeroplanes of the single engine or twin engine bombing class will not be taught items Nos. 10, 16 and 18 of para. 251 (i), but will only be instructed in the manœuvres leading up to a spin and the subsequent method of recovery.

367. The general rules governing flying instruction as laid down herein are not intended to apply only to preliminary instruction for pupils, but should be put into effect in a modified form whenever a pilot is required to learn to fly a new type.

CHAPTER V.—RIGGING.

General considerations.

368. This chapter is intended primarily for use at flying training schools in the instruction of pupil pilots. The detail of this subject is to be found in the rigging manuals and handbooks on particular types of aircraft. Chapter I contains the principles that govern the behaviour of an aeroplane in the air, but quite small variations in the different factors produce extremely important effects. The importance of good rigging cannot be over-estimated since bad rigging may not only lead to considerable loss of efficiency in speed and ability to manœuvre, but may even imperil the life of the pilot through placing undue strain on some vital part of the aeroplane. Although it is not necessary for a pilot to be an expert rigger, he should have sufficient knowledge of rigging to be able to supervise the rigging of an aeroplane and to be able to give instruction for such alterations to be effected as he may consider necessary.

Checking of centre of gravity.

369. To find the centre of gravity of an aeroplane, the aeroplane should first be set up as shown on Fig. 81, the

undercarriage wheels being supported on a platform weigher and the tail supported by means of a spring balance, the chord of the lower main plane being horizontal. A plumb bob is then dropped from the leading edge as shown.

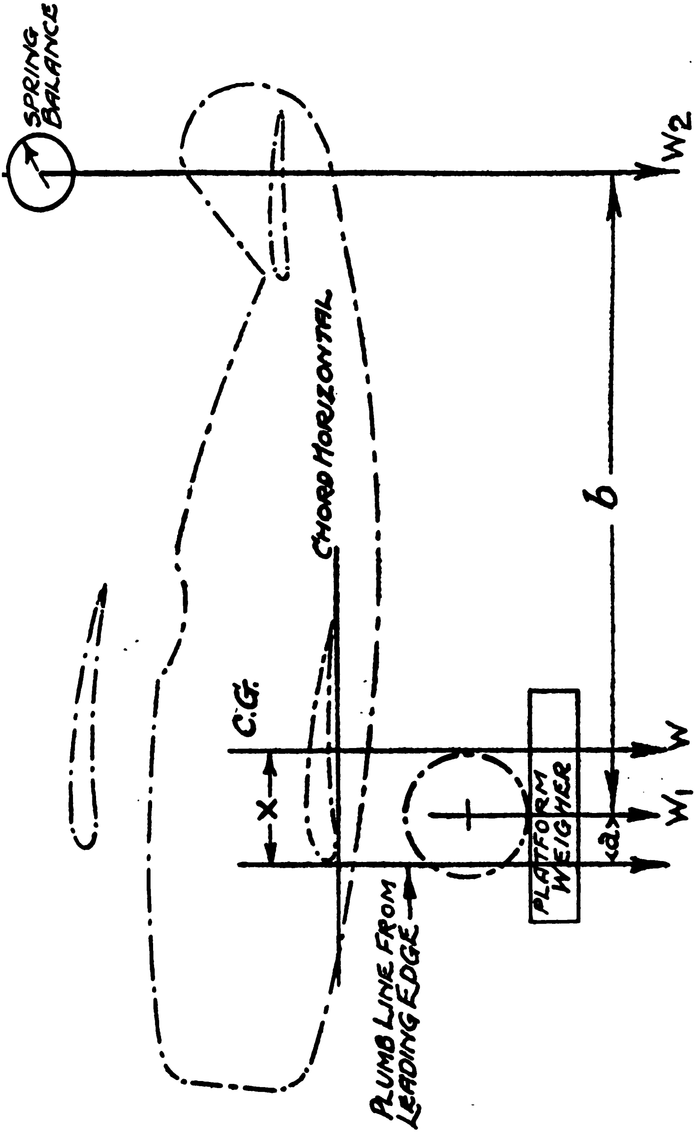

FIG. 81.

The following quantities are now measured:—

W_1 = Weight on platform weigher.
W_2 = weight registered on spring balance.

Then Total Weight of Machine $W = W_1 + W_2$.

a = horizontal distance from plumb line to centre of axle.
b = horizontal distance from centre of axle to line of application of tail load.

Let X be the distance of the C.G. behind the leading edge of the lower main planes on a line parallel to the chord.

$$\text{Then } X = \frac{W_1 a + W_2 (a + b)}{W}$$

This determines the distance of the C.G. behind the leading edge of the lower main plane measured parallel to the chord of the plane.

If, in addition, it is necessary to obtain the vertical distance of the C.G. from the chord of the lower main plane, the following method should be followed.

The tail of the machine should be lowered as far as possible as shown in Fig. 82. A plumb bob is again dropped from the leading edge of the lower main plane, and the following quantities measured :—

W_3 = Weight recorded on platform weigher.
W_4 = Weight registered on spring balance.
a_1 = Horizonta distance leading edge is in front of centre of axle.
b_1 = Horizontal distance from centre of axle to line of action of tail load.
θ = Angle of incidence of lower main plane.

Then total Weight of Machine $W = W_3 + W_4$.

Let X_1 = horizontal distance C.G. of the machine is behind leading edge of lower main plane in this position of machine (*see* Fig. 82).

$$\text{Then } X_1 = \frac{W_3 a_1 + W_4 (a_1 + b_1)}{W}$$

The dimensions X and X_1 and the angle θ all of which have now been definitely determined are shown transferred to one diagram in Fig. 83.

Reference to this diagram will show that the distance of the C.G. above the leading edge of the lower main plane on a line at right angles to the chord

$$Y = \frac{X_1 - X \cos \theta}{\sin \theta}$$

This determination must then be repeated with the tail raised as high as possible, but still, to give a positive reading on the spring balance, so as to verify the value of Y.

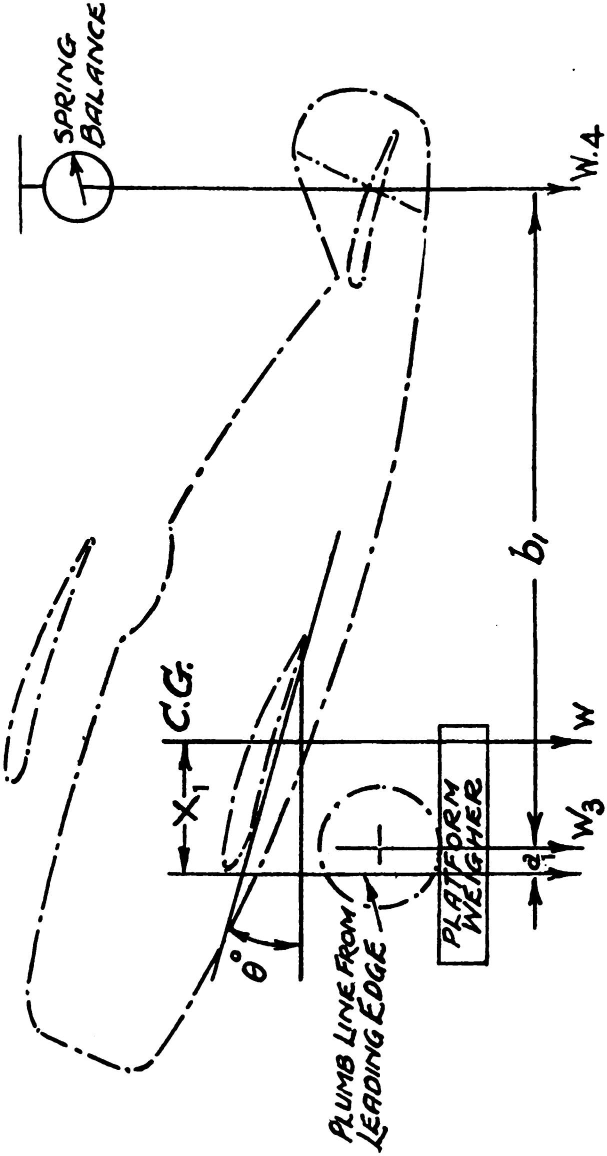

FIG. 82.

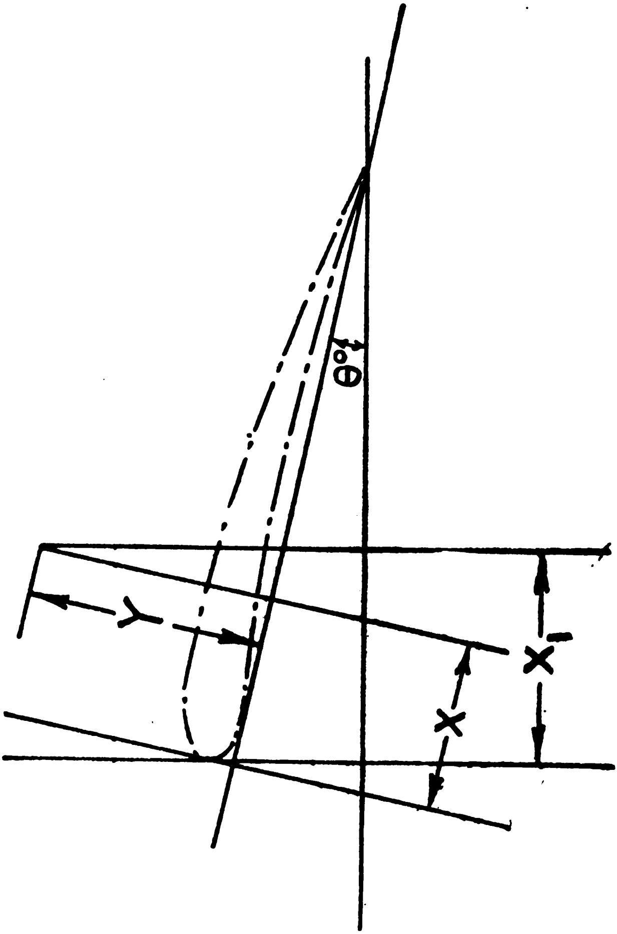

FIG. 83.

In carrying out the foregoing the following precautions must be observed.

(1) The aircraft should always be weighed in the "Tare" condition, *i.e.*, the weight of the complete structure together with its power plant in running order; (no petrol, oil or *reserve* water), flying instruments and all permanently fixed equipment.

(2) The machine should be weighed as far as practicable in still air, and no readings may be taken until the chocks have been removed from the wheels and precaution taken that the pull of the spring balance is absolutely vertical.

(3) Care should be taken to ensure the accuracy of the weighing appliances by suitable checks at reasonable intervals.

(4) In cases where multiple weighers are used, the component weights of the machine must be taken simultaneously.

The effect of incidence and dihedral upon stagger.

370. When an aircraft has a different degree of dihedral on the upper and lower planes, the stagger will not be constant throughout the span, because a plane which possesses a dihedral angle pivots about a line inclined to the horizontal at an angle which is governed by the angle of incidence. Thus an increasing set-back is given to the plane as it moves from a position of no dihedral to a limiting position of 90° dihedral angle, the circle described by the tip to the leading edge not being in a vertical plane. This effect is only found when the upper and lower planes have different dihedral angles and the set back is rarely of any great magnitude.

THE TRUING UP OF FUSELAGES.

371. The tendency seems to be towards providing aircraft with bodies that are assembled in jigs in the first place, and for which truing up after erection is only partially necessary or possible. The following pages deal with the truing of the still general type of box girder fuselage, consisting of four longerons and a number of vertical and horizontal struts, the whole being held together by adjustable steel bracing wires. (*See* fig. 84.) The principles laid down will serve as a guide for the truing up of other types of body, but it is not always possible with these other types to make all the adjustments enumerated. The tendency is for the rigging of a fuselage to become more and more a matter of assembling.

372.—(i) Before a fuselage can be trued up, it is usually essential to know the position of the horizontal datum line, that is, the line in the side elevation of the fuselage which will cut the side struts at certain known points. Generally, this line will be made horizontal when the fuselage is placed in rigging position for the purpose of erecting the wings, undercarriage and tail. It is very often found that the situation of this line is marked on the side struts of the fuselage frame during the construction of the fuselage by the manufacturer. For those aeroplanes that have the top surface of the upper longerons horizontal throughout, this surface will constitute the datum line and no marks giving the position will be necessary.

(ii) The form of the typical body generally agrees with one of the shapes shown in fig. 85, A and B, or is a combination of the two, as at C, all three drawings being side elevations. In B the horizontal datum line divides the fuselage into two symmetrical halves; in A the upper surface of the top longerons is the datum line; in C the datum line is parallel to the upper surface of the top longerons in the front half, and midway

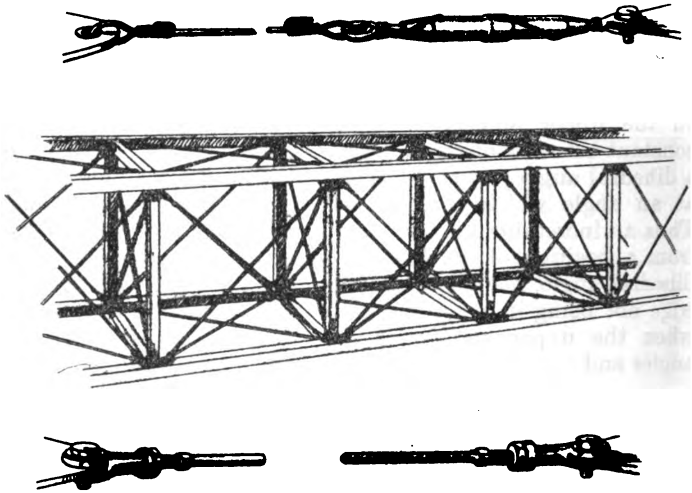

Fig. 84.—Braced girder type of fuselage.

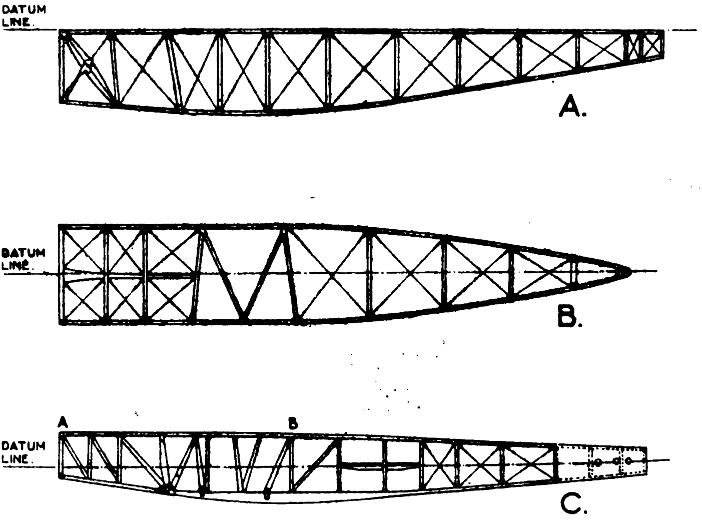

Fig. 85.—Types of fuselage design.

between outer surfaces of top and bottom longerons in the rear half. All fuselages are symmetrical about the centre line of the fuselage in plan.

373. To true up a fuselage of the B type, support the fuselage on two trestles, and, commencing at the front, check the length of the diagonal bracing wires in each of those side panels which are contained between vertical side struts. A pair of trammels should be used for this purpose, and, unless the rigger is quite certain that the wiring plates at the corners of the panels are all of equal length, he should use the intersection of the centre line of the longerons and the vertical struts for trammelling, marking these intersections with pencil. If the diagonals are not equal, slacken off the shorter diagonal wire before tightening the other. If this is not done, when the two wires are equalised in length, they will be at too great a tension. Before the panel is left both wires should be of the correct tension and of equal length. Follow this plan with all the bays from front to rear on one side, then from front to rear on the other side of the fuselage. The cross-panels should then be treated in a similar manner, using the edges of the longerons instead of the intersection of the centre line, and afterwards the top and bottom panels. When this has been done, the fuselage should satisfy the final checks for truth, which are carried out by stretching a line on each side from the point on the front vertical strut which corresponds to the position of the datum line, to a straight edge clamped across two of the last few struts, or to the sternpost, if horizontal, as shown in fig. 86. This line should be a few inches away from the side struts, and a carpenter's square held as shown will serve to check the truth of the fuselage sides.

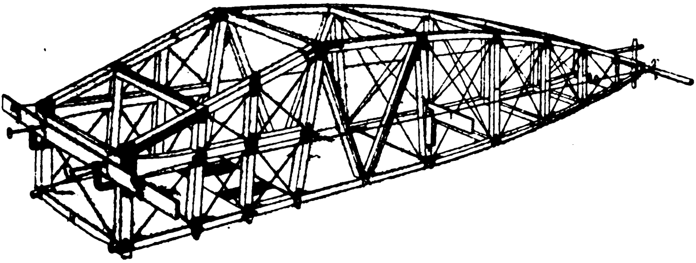

FIG. 86.—Truing up a fuselage.

374. Next stretch similar lines above and below the middle points of the horizontal cross struts, attaching the cords at the front to the foremost struts, and at the rear to the sternpost, or to a straightedge clamped in a convenient position with one edge vertical and in line with the centre line of the

sternpost. A plumbline dropped successively at each bay should just touch the stretched cords and the mid points of the horizontal struts. The trestles must be so arranged that the cross struts are horizontal to begin with, and it is often possible, before tanks and other fittings are installed, to stretch one cord through the middle of the fuselage instead of one above and one below. Finally, test the sternpost to see that it is vertical or horizontal, as the case may be.

375.—(i) A fuselage of the type shown in fig. 85A may be trued up on the same principle, but as the longerons are straight and are horizontal when the fuselage is in rigging position, they may be used instead of stretched lines for the truing of the side panels. If the top longerons are horizontal throughout their length, and the transverse diagonal bracing wires are equal in each cross section, then the fuselage sides may be taken as true. If not, adjust the diagonal facing of the side panels until the upper longerons are straight and horizontal. Adjust the transverse bracing, making the diagonals equal, and check for truth of fuselage in plan as in the first type.

(ii) Some fuselages do not conform to either type, but are a compromise between the two. The Avro and D.H. 9A possess fuselages of this kind, the top longerons from A to B being horizontal when the fuselage is in rigging position, and the part of the body to the rear of B being symmetrical about the centre line in side view. (*See* fig. 85C.)

(iii) To true up a fuselage of this kind, adjust the trestles until AB is horizontal, and mark the mid points of the struts from B rearwards. Then proceed as in the first type, making sure that the marked mid points to the rear of B are opposite a stretched cord, and that the upper longerons from A to B are straight and horizontal, *i.e.*, vertical distances from A to the datum line and from B to the datum line must be equal. In those fuselages that consist of two separate halves afterwards joined together, true up each half separately, then make the joint and true up the panels where the joint occurs. Afterwards check the whole body for alignment. This final check should normally be applied by dropping plumblines from the middle points of two or three of the upper horizontal cross struts, one at the front of the fuselage and the others at intervals behind, also a plumbline from the centre line of the sternpost. These lines should all touch the middle points of the corresponding lower horizontal cross members, and also touch a line stretched near the floor between heavy weights, the line to correspond with the plan centre line of the fuselage.

376. It is sometimes useful to get the trestles upon which the fuselage is supported dead level first, then check the

fuselage by putting straightedges across the top longerons at various points, testing with a level. It is necessary to see that both trestles and straightedges are at right angles to the centre line of the fuselage in plan.

377. There are several general matters to which very special attention should be given. In the first place, it is necessary to ensure that the ends of the cross struts are cut off at the exact angle at which the longeron meets the strut. Secondly, the strut must be properly bedded home in its socket. As a preliminary to this, it is necessary to make sure that the bottom of the socket is perfectly even and clean, and, if the socket is a metal one of the welded type, to see that no blobs of metal have been left inside the socket. If any inequality is left inside a socket, the strut will appear to be firmly pressed home, whereas the extra load that will be put upon the joint under certain conditions will force the strut further into the socket, thus causing slack wires and putting the structure out of truth.

378. Thirdly, before the fuselage is left, all the bracing wires must be as near the correct tension as possible. The judgment of the correct tension is largely a matter of experience, and pupils should lose no opportunity of testing the tautness of wires that are passed by experienced men as correct in tension. It is important that the wire should not be too tight, as this naturally places a preliminary stress on compression members and may even bend them. On the other hand, a wire that is too slack will, when stretched, fail to perform its duty and throw extra stress on other parts of the structure.

TRUING OF WINGS, CONTROL SURFACES AND UNDERCARRIAGE.

Truing up a main plane.

379.—(i) Most planes are assembled in jigs from their component parts, and this method ensures that the plane shall be true when assembled. It is quite a simple matter, however, to true up a plane which has been taken apart for any reason and reassembled without a jig.

(ii) The framework of the usual type of wing consists of two spars, generally parallel, held apart by compression members, which are sometimes of steel tube and sometimes box-form ribs of three-ply, and occasionally wooden struts. The space between the spars is braced by steel tie rods or piano wire, the strength of which gradually diminishes from the wing root to the tip. The remaining units—the leading and trailing edges and the ribs—are chiefly provided to preserve the shape of the wing; it is the braced unit consisting of the spars and compression members that gives strength to the structure.

380. To true up, lay the plane across two trestles, placing packing blocks on the trestle tops so that the weaker parts of the plane are clear of the trestles, and, commencing at the wing root, adjust the diagonal bracing until trammels show that the diagonals are equal in each bay. Then test the spars for straightness, preferably with a long straightedge, but if this is not available, a tightly stretched cord may be used. If the spar or any other part of the wing is not true when the bracing is correct, a new wing, or at least new spars, will be required.

381. The truing-up of such components as tail-planes, elevators, ailerons and rudders follows the general lines laid down in the preceding paragraph for the truing up of main planes. Unless the inaccuracy or damage is very slight, it is better to replace the complete unit, as is generally done. Before passing the plane as ready for covering, it is necessary to make quite sure that all turnbuckles are locked, and that no chafing of wires through vibration is possible.

Truing up the undercarriage.

382.—(i) The most common type of undercarriage in use at present consists of two similar Vs of wood or steel joined at the bottom by struts or distance pieces, with an axle of steel tube free to work vertically in slots provided at the lower ends of the Vs. As a rule, the front panel is braced diagonally (*see* fig. 87).

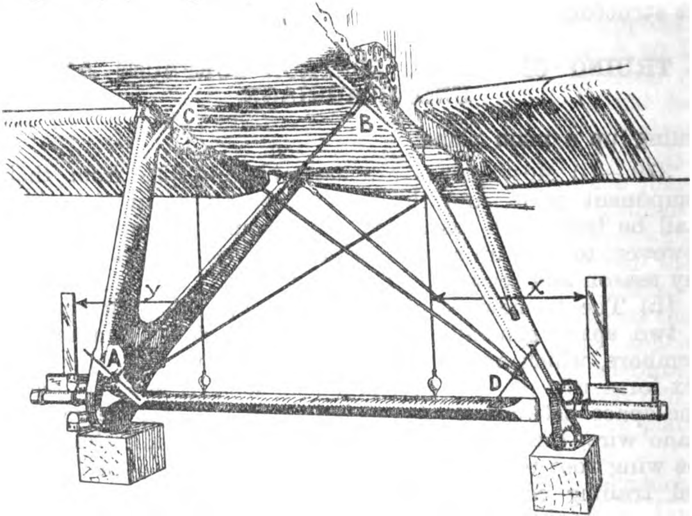

Fig. 87.—Truing up an undercarriage.

(ii) The undercarriage should be assembled before it is attached to the fuselage, particular care being taken to make sure that the V-struts, if of wood, are bedded well home in their sockets. When the four fuselage attachments are made, adjust the bracing wires AB and CD to equal length, checking by trammel. The undercarriage should then be true. To verify, drop plumblines from the fuselage lower longerons to the centre line of the axle tubing, and measure along the axle from these points to the inner flanges of the wheel hubs *x* and *y* in fig. 87. When the axle is central with the fuselage the distances should be equal on each side. A further check can be made by comparing the distances from the axle extremities on each side to the sternpost.

(iii) Where one or two skids are built into the undercarriage care must be taken that the skid, if a single one, follows the centre line of the fuselage in plan view, and that the angle of the skid to the horizontal, in elevation, is accurate. If two skids are provided, they must both be parallel to the centre line and equidistant from it.

Oleo type undercarriage.

383. For many years experiments have been made to find a satisfactory substitute for the usual type of elastic-sprung V-pattern undercarriage, and many different types of oleo undercarriage have been designed. These have one common feature, *viz.*, a cylinder filled, or partially filled, with oil, in which a piston slides, compressing the air where air is designed to be present and forcing the oil through small orifices, thus absorbing the shock of the impact between wheels and ground. Arrangements are made to allow the oil to pass the piston, generally by means of valves, the piston being returned to its original position, either by a coil spring or compressed air.

384. From the rigging point of view, these undercarriages are very easy to fit. After the rigid portion of the undercarriage has been attached and trued up, the fuselage is supported on trestles at a greater height from the ground than would be necessary for the usual V-type undercarriage, and the attachments between the tops of the undercarriage oleo struts and the fuselage are then made. No further truing up is, as a rule, necessary or possible.

ASSEMBLING AND TRUING UP A COMPLETE TRACTOR BIPLANE.

Fuselage.

385.—(i) The first component to be assembled is the fuselage. The method of assembly varies in detail for different aeroplanes, but in those fuselages which are of the braced girder type it is usual to assemble the upper and lower longerons on one side, together with the intervening vertical struts, and, when each side is approximately trued to fit in position, the horizontal cross struts, and last of all the transverse cross bracing. The complete fuselage is then trued up, and the internal fittings of the fuselage built into position.

(ii) The engine bearers are usually fitted at this stage, as well as tanks, controls and seats. The fuselage is supported on trestles during this operation, the height of these trestles being adjusted so that it is possible to fit the undercarriage at the same time. The undercarriage Vs are then fitted into position and trued up and the attachments to the fittings on the fuselage longerons completed. At the same time as the fuselage internal fittings are being fixed, it is usual to fit the tail-planes, fin and rudder. The final truing up of the empennage is better left to a later stage, when it may be checked for symmetry against the wings.

386. The centre section is the next component to be erected. The upper centre section plane should be placed upside down on a piece of felt on the ground, and the four centre section struts bedded well home in their sockets. Bracing wires should be attached and the whole unit lifted into position. The loose ends of the struts are next introduced into their respective sockets and well driven home. The loose ends of the bracing wires can now be attached.

387. At this time the fuselage should be placed in rigging position (sometimes called flying position). As an aeroplane can fly in almost any attitude, it is preferable to use the term "rigging position." Specific instructions are usually given to enable the rigger to place the fuselage truly in rigging position. Occasionally a horizontal line is painted, or wood or metal blocks are screwed on to the fuselage side so that the rigger may know that the fuselage will be in rigging position longitudinally when this line is horizontal. This datum line will almost invariably be parallel to the datum line used for truing up the fuselage. The level at which the datum line is painted does not, of course, affect the attitude of the fuselage.

388. Laterally, the fuselage is in rigging position when the spars, where they pass through the fuselage, are horizontal. In the absence of specific instructions as to the rigging position, the centre line of the airscrew shaft should be made horizontal and the incidence of the lower planes at the centre section checked to see if the angle of incidence is correct for the particular aircraft. The lateral level may be assumed to be correct when a straightedge placed across the upper or lower longerons or centre section spars is horizontal. There is a

recent tendency towards the restriction of the use of the datum line to the truing up of the fuselage only, and to the referring of the angles of incidence of the tail plane to the incidence of one of the main planes. The incidence of the lower plane would generally be taken as the key to which other angles, including the angle of the tail plane and that of the remaining main plane, or planes, would be referred. The Siskin III follows this tendency, but here the incidence of the upper main plane is chosen as the key angle, as the lower planes have only a single spar.

389.—(i) Care should be taken in choosing the positions for the supporting trestles, unless such positions are marked. It is always safe to place the front trestle at the front undercarriage struts, where a strong bulkhead or cross strut is found, and for the rear trestle to choose the position where the fuselage is strengthened to take the stresses due to the tailplane and tailskid. The height of the rear trestle, if not of both, should be adjustable, and the rear trestle should be adjusted until the datum line is approximately horizontal.

(ii) Packing pieces should next be placed under one or both of the lower longerons at the front and rear trestles, if necessary, until a spirit level placed on some convenient horizontal cross strut shows it to be horizontal. These packing pieces should be substantial, so that the fuselage is as rigid as possible. Extra time spent in this direction will be well repaid when the wings are attached, as flimsy packing will necessitate the fuselage being levelled all over again.

390. When the transverse levelling is correct, the longitudinal levelling should be looked to once more, until the fuselage is securely fixed and is levelled transversely and longitudinally. If the undercarriage has been attached before this stage, packing blocks will be placed under the V-struts. To true up the centre section, trammel the front and rear cross bracing wires until the upper centre section plane is horizontal, and is symmetrical about the vertical centre line of the aeroplane when viewed from the front. If the planes possess any degree of stagger, the adjustment can be made by means of the side cross bracing wires.

391.—(i) The methods of checking are as follow :—Drop a plumbline from the extremities of the front and rear top centre section spars, and measure the gap between these plumblines and the lower longerons, the measurements being made at right angles to the lower longerons. The stagger may be checked approximately by measuring the fore and aft horizontal distance between the plumbline dropped from the upper centre section front spar, and the corresponding point on the bottom centre section spar. (*See* fig. 88.)

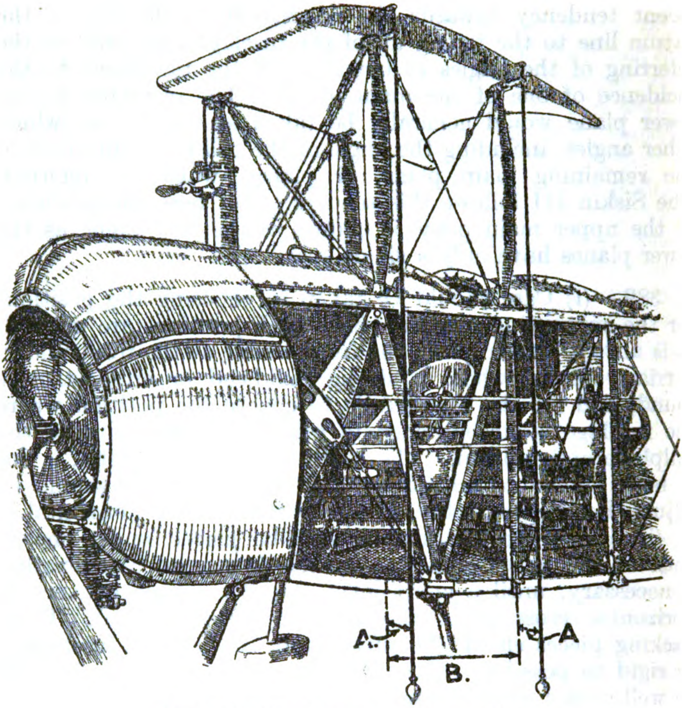

FIG. 88.—Truing up a centre section.

(ii) At this stage it is advisable to leave the centre section adjustments only approximately correct, and not locked, as the operation of fitting the main planes is thus facilitated.

Attaching main planes.

392. There are two commonly used methods of mounting the main planes in position, the choice between these two methods being decided by such factors as the number of men available, the time allowed, the strength of the roof of the shed in which the operation is performed, and the availability of lifting tackle of requisite strength.

393.—(i) In the first method the lower main plane should be placed with its chord vertical and the leading edge resting on the ground. Strips of wood and felt or some other suitable material must always be placed on the ground to protect the leading edges from injury. The interplane struts should next be fitted to their respective attachments, and the upper main plane brought into its proper position in relation to the lower, so that the interplane struts can be attached to this plane also. The bracing wires are supplied already cut to length and should be joined to their respective fork ends. In this way the complete box of planes for one side will have been boxed up into a fairly rigid structure that can be handled quite easily, provided that sufficient lifting power is available. The planes should be hoisted into position and the spar attachments to the centre section and longerons made. It is at this stage that a little freedom in the upper centre section bracing is of assistance. As soon as the plane spar attachments for one side are made, the inner landing wires running from the upper centre section to the bottom of the inner pair of interplane struts should be attached. Later the inner flying wires should be joined up, and the same action taken on the other side of the aircraft.

(ii) The second method of erecting the main planes is to fit the lower main plane spar attachments to their companion fittings on the fuselage, supporting the end of the plane in the meantime on the trestle. As soon as possible the inner landing wires should be attached. The interplane struts should then be assembled to the upper main plane away from the aircraft, and the spars of the upper main plane then joined to the spars of the upper centre section. While this is being done, the upper main plane can be supported by being slung from the roof of the shed or in any other convenient manner. The rigger should not on his own responsibility use the roof of a shed for supporting any appreciable load, and the advice of a competent technical officer should always be sought when no other method of slinging is available. Substantial and carefully-arranged props must always be used to carry the load to the ground, as roof structures are not designed to take stresses other than those imposed by the nature of the building and by weather conditions. The interplane struts should next be fixed to the lower plane, and the bracing wires attached and tightened sufficiently to make the structure reasonably rigid. When this has been done the transverse and longitudinal levelling of the fuselage should again be checked, and if found true the final truing up of the upper centre section proceeded with. The centre section must be absolutely correct in rigging before any attempt is made to true up the main planes.

Truing up main planes.

394. The dihedral of the lower main planes is fixed by the adjustment of the front landing and flying wires, and is checked by means of a straightedge and Abney level or clinometer. The stagger is decided by the adjustment of the cross bracing between the front and rear interplane struts, and is checked by measuring the fore and aft distance between a plumbline dropped from the leading edge of the upper main plane and the leading edge of the lower main

plane. The incidence is obtained generally by adjusting the rear landing and flying wires, and is checked by a clinometer resting on a straightedge which is pressed against the lower surface of the plane, at one of the ribs. No attempt should be made at first to make the incidence, dihedral and stagger absolutely correct, because they are interdependent, and adjustment of one of the three is liable to upset the results already obtained. When all three are approximately correct the final truing up can be begun. Before leaving the wings it is necessary to verify that—

(i) the leading edge of the main planes on port and starboard are in one straight line (this only applies to planes that have no dihedral, and do not possess sweepback);

(ii) the distance measured on each side from some convenient fixed point near the tip of the plane to a third fixed point on the centre line of the fuselage near the tail-skid is equal; and

(iii) the incidence, dihedral and stagger on each side is correct.

Truing up the tail planes.

395. The fin and rudder must be vertical, the centre line of the fin must usually coincide with the centre line of the fuselage, and the tail-plane must be horizontal. If the spars are not tapered this is very easily checked with a straightedge and spirit level. If the spars are tapered it is necessary to know the height of the packing blocks, that must be inserted, and the positions of these blocks, before the straightedge and spirit level can be used. The tail-plane spars must be square with the fuselage and this may be checked by taking measurements on each side from the tips of the tail-plane spars to a convenient pair of fixed points of the fuselage, as for instance, the front or rear spar attachments of the lower main planes If the measurements taken are equal and the tail-plane spar is in one straight line, this spar will be at right angles to the centre line of the fuselage.

396. Occasionally, but rarely, the designer will have the fin offset from the centre line of the fuselage for aerodynamic reasons. When this is done, the rigging directions will always specify the angle between the longitudinal centre line of the fuselage and the fin centre line. Instead of the fin, the centre line of the engine may be offset, but specific directions will be given whenever this is so.

Controls.

397.—(i) The controls should be connected up and the turnbuckles adjusted, so that the cables are fairly taut but work without undue stiffness.

(ii) Ailerons are often given a preliminary droop, *i.e.*, the trailing edge of the aileron is set a little lower than the corresponding trailing edge of the plane. As an average the amount of droop is from ½ in. to 1½ in., dependent on span.

(iii) The control column is not always vertical when the elevators are in line with the tail-plane. Frequently the column leans forward at a certain angle to the vertical when it is normal, but the rigger will always follow the specific instructions dealing with the individual aircraft on these points. After connecting up, the rigger should sit in the pilot's seat and operate all the controls one at a time to see that the full range of movement is obtained and that the control surface moves in the right direction following a corresponding movement of the rudder bar or control column. Care must be taken that a forward movement of the control column drops the elevators, as the cables have sometimes been incorrectly connected up.

Doping.

398. Fabric parts are doped in order to make them taut, weatherproof and to minimise skin friction. All fabric parts must be kept clean and free from oil to prevent deterioriation. Holes in fabric must be repaired at once. If the hole is small, a piece of fabric can be redoped over the hole. If the hole is large it will be necessary to sew the patch in and dope another over it. The area round the patch should first have the old dope removed by means of a dope solvent, and the patch should have its edges frayed before being doped in position.

PRACTICAL POINTS.

Turnbuckles.

399. A turnbuckle is composed of a barrel with left-hand thread at one end and right-hand thread at the other, into which are screwed fork or eye bolts. The bolts must be a good fit in the screwed ends of the barrel. Turnbuckles must not be worked upon with pliers or other tools. A wire, passed through the hole provided in the barrel, must be used for adjusting them. Under no circumstances is it permissible to cut off any portion of a turnbuckle. Turnbuckles should be locked with soft iron wire passing through the eyes and the hole in the barrel, in such a manner as to oppose the tendency of the turnbuckle to unscrew.

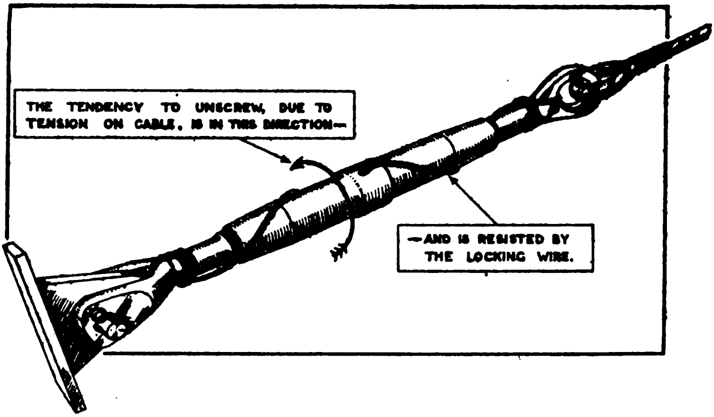
THE TENDENCY TO UNSCREW, DUE TO TENSION ON CABLE, IS IN THIS DIRECTION—
—AND IS RESISTED BY THE LOCKING WIRE.

FIG. 89.

Streamline wires.

400.—(i) The section is not quite of streamline form, for the obvious reason that until the final adjustment is made it is not known which edge of the wire will be the leading one. The section is therefore symmetrical, the object being to minimise head resistance. Streamline wires should be free from kinks or bends and should show no signs of having been previously bent and straightened. When fitted with plain fork joints, the wires must be threaded through the barrel of the fork end to an extent sufficient to cover the inspection hole provided in the barrel. Final locking is effected by the lock nut.

(ii) Streamline wires are locked by means of small nuts. Care should be taken that these are not too tight, as the threads may be stripped or injured. It should be remembered that the main plane bracing wires bear considerable loads during various manœuvres and in consequence the importance of the security of the various wires cannot be over-estimated.

When putting in bracing wires, care should be taken that an equal number of threads are engaged at each end of the wire.

Shock absorbers.

401. Undercarriage shock absorbers should be of equal tension. This may be tested by allowing the weight of the aeroplane to come on to the wheels, and testing whether the axle and centre section spars are both horizontal at the same time, and therefore parallel. Shock absorber cord is liable to break when pulled over narrow tubes, or small radius bends, and this should be avoided so far as possible.

CHAPTER VI.—ENGINES.

ENGINES.

General remarks.

402. This chapter is intended primarily for use at flying training schools in the instruction of pupil pilots. The detail of this subject is to be found in the internal combustion engine manual and handbooks on particular types of engines. A sound knowledge of the principles of an internal combustion engine is essential to a pilot, as it forms the foundation on which a proper training in practical work is based. Not only should the pilot be able to check the adjustments and repairs made to the engine, but he should be able to carry out minor repairs himself in the event of a forced landing through some trivial cause. Even if he is unable to remedy the defect, the pilot will often save the nearest unit considerable time and trouble by letting them know the exact cause of the failure and the spares required to make the engine serviceable.

The principle of the engine.

403. The parts of an engine are :—

(i) A *piston*, which slides to and fro in a *cylinder*.

(ii) A *crankcase*, in which is enclosed a *crankshaft* mounted on *bearings* and free to rotate. The sliding motion of the piston is converted into a rotary motion of the crankshaft by means of a *connecting rod*.

(iii) An *inlet valve*, through which the gas enters the cylinder.

(iv) An *exhaust valve*, through which the burnt gases escape.

(v) A *camshaft*, which operates the valves as required.

(vi) A means by which the camshaft is driven from the crankshaft.

(vii) A *carburettor* to mix petrol and air to form a combustible mixture.

(viii) An *electrical device* for producing an electric current.

(ix) A *sparking plug* for igniting the mixture.

404. The object of a petrol engine is to develop a maximum of power with a minimum of weight in a small space. Fuel in gaseous form, combined with air, is introduced into the cylinder wherein the full heat of combustion is imparted directly to the mixture. The combustible part of the charge must be mixed with a sufficiency of air to ensure complete combustion of the hydrogen and carbon elements. A high

excess of air weakens the combustion, and a scarcity of air causes waste of fuel. In practice, an excess of air is the most usual. The liquid fuels most widely used are derived by distillation from crude petroleum, and most of them are pure hydro-carbons. The most volatile, petrol, vaporises at ordinary atmospheric temperatures, and is therefore used in engines which are required to start at a moment's notice. The specific gravity ranges from ·680 to ·760. Benzol, which is as volatile as petrol, is a distillate of coal, is a pure hydro-carbon, and forms a good fuel for internal combustion engines. A mixture of these two fuels is in general use.

405. The majority of internal combustion engines use the four-stroke cycle—that is, one power stroke and three other strokes in each cycle. To obtain an even torque and greater flexibility in running, multiple cylinders are used.

The four strokes are :—

(i) The downward suction stroke.
(ii) The upward compression stroke.
(iii) The downward power stroke.
(iv) The upward exhaust stroke.

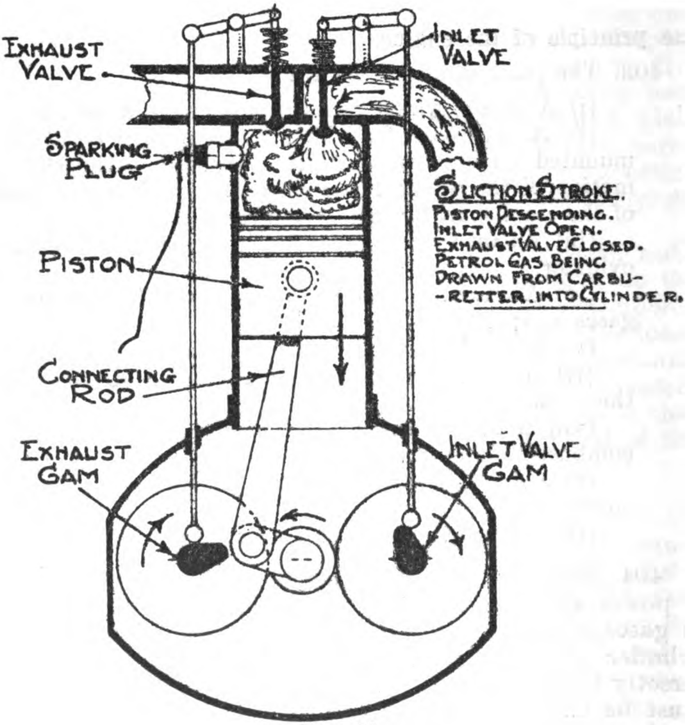

FIG. 90.

(i) *The downward suction stroke.*—As the piston travels down the cylinder, the inlet valve is opened by the cam and the piston sucks in a mixture of petrol and air from the carburettor. Shortly after the piston reaches the bottom of the stroke the inlet valve is made to close.

(ii) *The upward compression stroke.*—The piston now rises in the cylinder, forcing the gas upwards and compressing it into a small space. On this stroke both valves remain closed. When the piston is almost at the top of its stroke the gas is ignited by a high-tension current of electricity jumping across the points of the sparking plug.

(iii) *The downward power stroke.*—The effect of the ignition of the gases is to cause a large increase in the temperature of the gases. Due to this increase of temperature, the expanding gases act on the top of the piston, driving it down the cylinder and thereby rotating the crankshaft through the medium of the connecting rod. When the piston is approach-

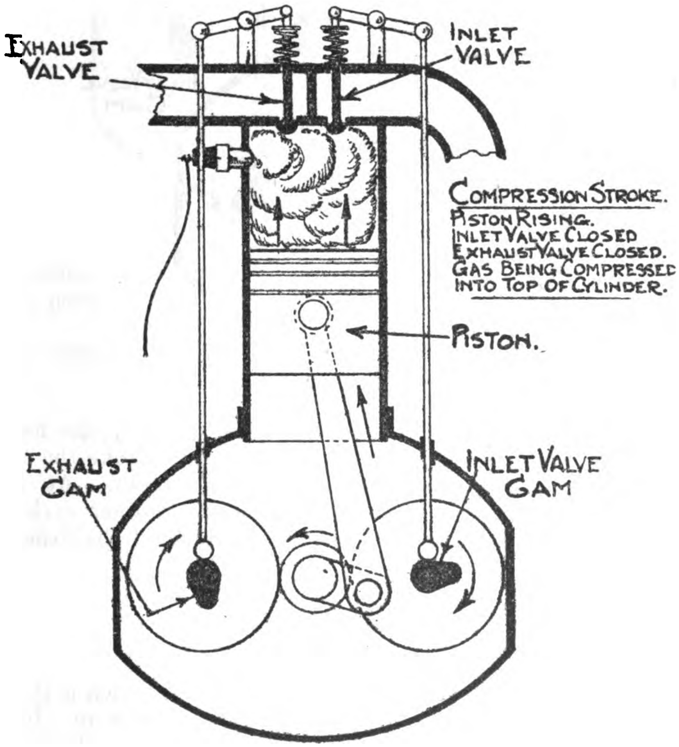

FIG. 91.

ing the bottom of the stroke, the exhaust valve is opened, allowing the gases to escape.

(ii) *The upward exhaust stroke.*—With the exhaust valve already opened, the piston rises in the cylinder, sweeping the burnt gases out. It is impossible to expel all the burnt gases, for when the piston is at the top of its stroke the contents of the combustion chamber still remain. At this position the piston is ready to commence another cycle of operations, and as the piston begins to descend the exhaust valve closes.

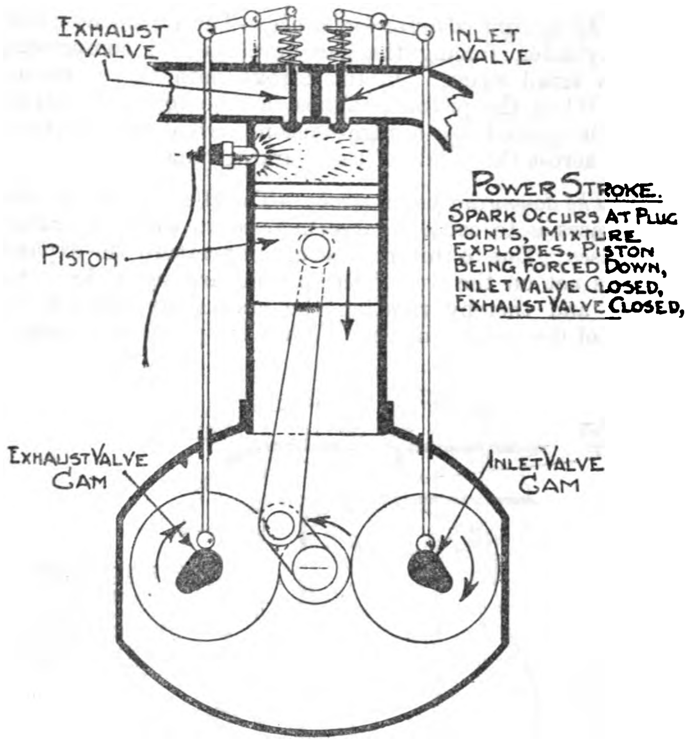
Exhaust Valve
Inlet Valve
Power Stroke.
Spark Occurs at Plug Points, Mixture Explodes, Piston Being Forced Down, Inlet Valve Closed, Exhaust Valve Closed,
Piston
Exhaust Valve Cam
Inlet Valve Cam

Fig. 92.

ENGINE DETAILS.

Piston.

406. The piston is a sliding piece of metal which is either driven or acts against the petrol-mixture pressure. It is guided by a cylindrical bearing surface, *i.e.*, the cylinder walls. Pistons are usually made of cast iron or aluminium alloy.

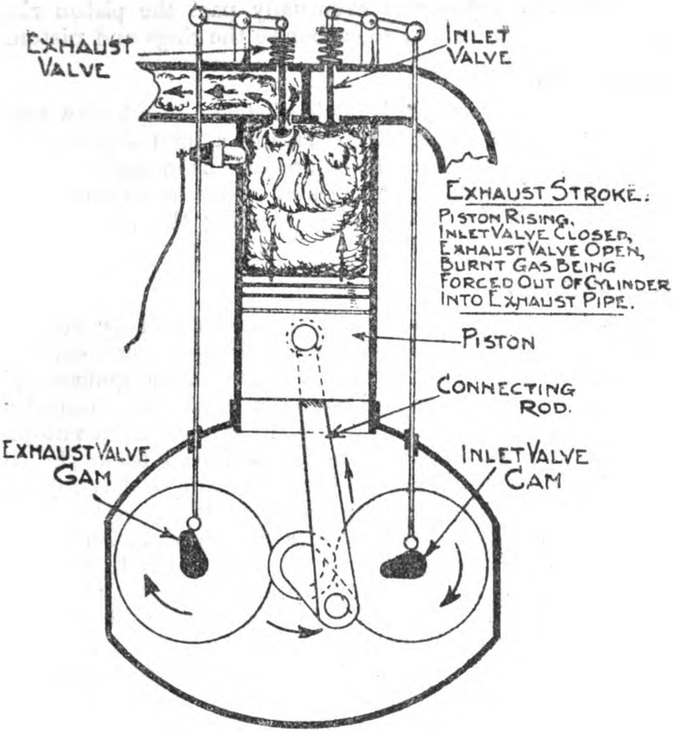

FIG. 93.

Aluminium alloy is used to reduce the weight of the reciprocating parts.

Piston rings.

407. To prevent leakage of the petrol mixture between the piston and cylinder walls, split cast-iron spring rings are fitted. These are located in grooves cut in the top of the piston and press against the cylinder walls. The number of rings used varies according to the design of the engine and the type of rings. The joint where the piston ring is split is cut at an angle of 45°, the reason for this is that it prevents a ridge wearing in the cylinder wall where this joint reciprocates. The width of the gap is laid down by the manufacturer and should be strictly adhered to. A general rule is $\frac{1}{16}$ in. to every foot of diameter.

Scraper ring.

408. This ring is similar to the piston ring, and is fitted on the bottom of the piston. It prevents an excess of oil

getting to the piston and eventually past the piston rings, where it would burn and so carbonise the rings and piston.

Gudgeon pin.

409. The gudgeon pin is made of steel: it is hollow and is generally parallel-sided. It is usually a light driving fit in the bosses of the piston. There are various means of securing it; generally this is done by locking plates or set bolts. The gudgeon pin is the means of connecting the piston to the connecting rod.

Connecting rod.

410. The piston is joined to the crankshaft by means of a connecting rod. This rod has a bearing at each end; the top is known as the small end, and fits on the gudgeon pin, the bottom as the big end and fits on to the crankshaft. The small end of the connecting rod is fitted with a phosphor bronze bush. This bush is usually a forced fit in the connecting rod. The big end of the connecting rod is split and carries two semicircular phosphor bronze shells lined with white metal. The white metal is machined to within ·002 or ·003 in. of the size of the crankshaft and is then scraped until a perfect bearing surface is obtained. In V-type engines two rods are connected to one throw of the crankshaft, *e.g.*, in the Liberty engine, by means of one connecting rod big end forked to fit over the other, and in the Rolls Royce, by means of an articulating rod—that is, one rod pin-jointed to the big end of the other.

Crankshaft.

411. The crankshaft of an engine is machined from a solid forging of very high quality steel. It revolves in main bearings which are carried in the crankcase. The part that runs in these bearings is called a journal. The part that carries the connecting rod is called the crankpin, and the part connecting the journal and crankpin is called the crank web. The crankpins are placed on one side or other of the centre of the crankshaft, their exact distance from the centre depending upon the length of the stroke of the engine. In aero engines the journals and crankpins are bored for lightness and the bores sealed. The oil communication between the journal and crankpin is by ducts drilled in the crank webs (*see* lubrication, fig. 115).

Crankcase.

412. Crankcases are usually built up of two aluminium alloy castings, the joint of which occurs in a horizontal plane through the axis of the crankshaft. The upper half of the casing provides the seatings for the cylinders. Crosswebs

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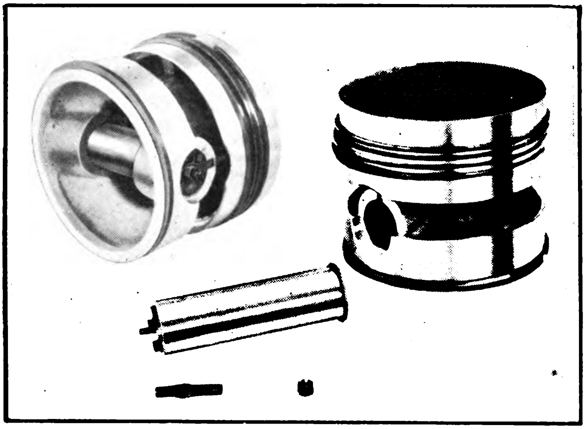

FIG. 94.—Eagle VIII. Piston and Gudgeon Pin.

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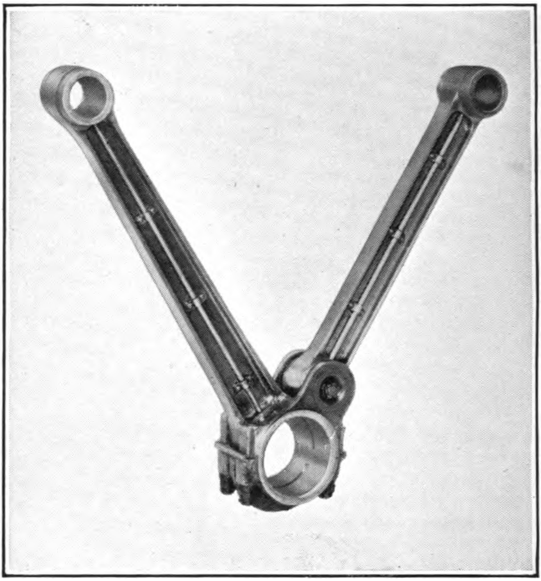

FIG. 95.—Eagle VIII. Connecting Rods.

are cast transversely across each half and are machined to carry the crankshaft bearings.

Cylinder.

413. The cylinder is usually a machined steel forging for water-cooled engines and iron casting for air-cooled engines. A cylinder is closed at one end and open at the other; the open end is bolted to the top of the crankcase. Inside the cylinder slides the piston. In order to reduce friction the walls of the cylinder must be extremely smooth and highly polished. The closed end of the cylinder is called the combustion chamber. In this chamber are fitted the two valves, the inlet and exhaust valves. The inside diameter of the cylinder is called the bore of the engine, and the distance the piston moves from top to bottom inside the cylinder is termed the stroke of the engine. In water-cooled engines the upper portion of the cylinder has an inner wall and an outer wall. The space between these two walls is filled with water (*see* cooling systems, fig. 99); the outer wall is called the water jacket.

Camshaft.

414. Camshafts are made of a good class of steel forging, and generally have machined integrally with them the cams for operating the rockers of the inlet and exhaust valves. These shafts are bored throughout their length. The camshaft is supported in bearings located in the camshaft casing.

Valve rockers.

415. These are machined from good class steel forgings. They are supported at their centres by a small bearing. One end is resting on the cam and the other end operates on the valve stem. At the valve stem end it is made adjustable, so that the clearance between the rocker arm and tappet can be maintained correctly.

Valves.

416. These are made of a special steel. A valve is a piece of steel which, when working, opens and closes a hole in the cylinder. The top portion is termed the head of the valve and the other portion the stem. The valve stem slides up and down inside a valve guide. This guide is securely fixed to the cylinder. It is usually made of cast iron, but occasionally of phosphor bronze. The valve is generally held in position by means of springs and washers. The valve is opened by the cam and is closed by the spring or springs. It is important that valves should not be too slack in their guides, slackness between the inlet valve guide and stem causes air to be drawn into the cylinder, which results in a

weak mixture. Valves should be kept in a good condition; no pitting or scoring should be seen on the valve seatings.

Water pump.

417. These are generally of the centrifugal or rotary type. The rotor consists of a number of curved blades, or vanes, which project from a brass plate. This fits inside a water-tight casing and rotates at great speed, and is driven from the crankshaft by gearing. The water enters the pump at the centre of the revolving plate and is thrown outwards by the movement of the vanes and thence is led by a pipe to the lower part of the water jacket of the cylinders.

Air pump.

418. This usually takes the form of a reciprocating plunger pump, in which the piston is operated from an eccentric driven from some part of the engine; in some cases it is driven by an airscrew. On the top of the cylinder are two non-return valves, one adjustable so that the air pressure can be regulated, and the other leading through the pipe-line to the tank. When the piston is nearly at the bottom of its stroke it passes holes drilled in the cylinder, which are in direct communication with the atmosphere. On the up-stroke the air is compressed and forced along the pipe-line to the tank. When the pressure in the tank is equal to the pressure at which the adjustable valve is set, the compressed air passes out of the adjustable valve to the atmosphere.

Timing diagram.

419. An average valve and ignition timing diagram is shown in fig. 98. The inlet valve is opened just past T.D.C. The piston has already commenced the downward suction stroke. The lag in the valve opening creates a slight depression in the combustion chamber and assists in overcoming the inertia of the gases in the induction pipe. The speed of the descending piston is greater than the speed of the incoming gases, so that a slight depression is still in the cylinder when the piston is at the bottom of its stroke. The valve is, therefore, kept open until the pressure in the cylinder is equal to atmospheric pressure. This position is approximately 40° past B.D.C. The lag in the valve closing increases the amount of charge entering the cylinder.

420. On the power stroke the exhaust valve is opened about 45° before B.D.C.: at this point the expanding gases are exerting little pressure on the piston head. When the crank is at an angle of 45° to the vertical, the angle between the connecting rod and the crank arm is so small that the

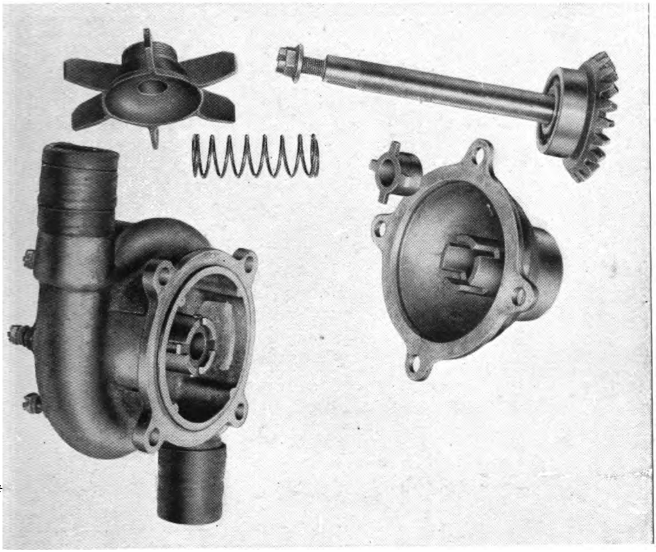

Fig. 96.—Water Pump (shown dismantled).

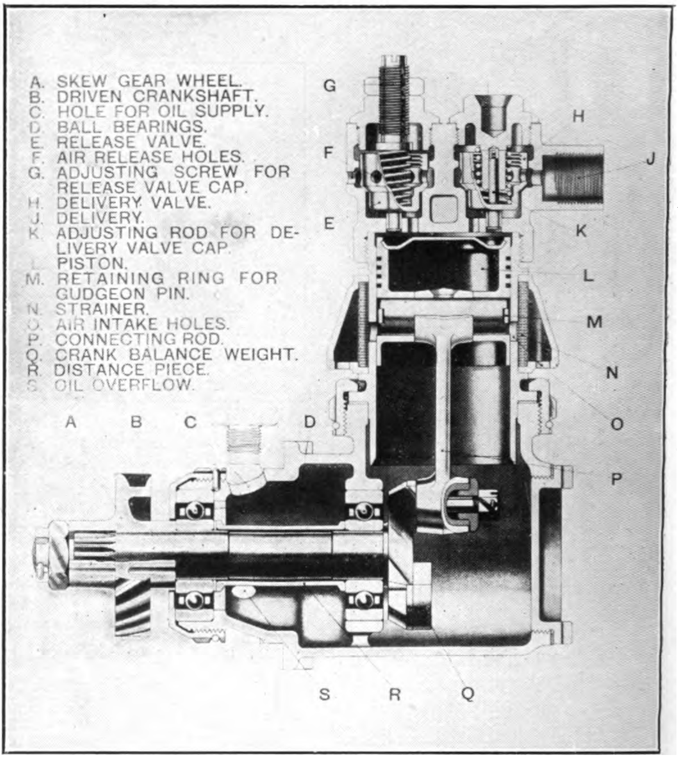

FIG. 97.—Eagle VIII. Air Pump.

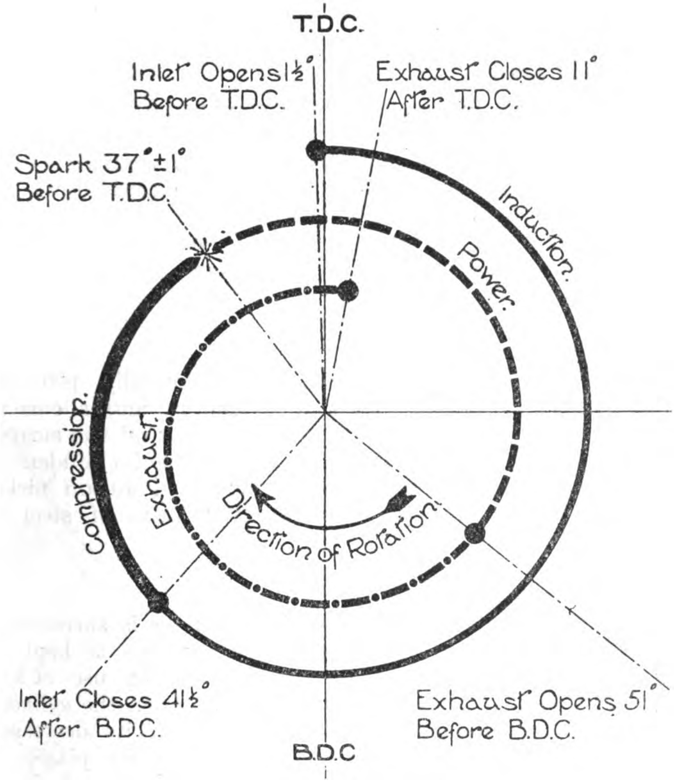
T.D.C.
Inlet Opens 1½° Before T.D.C.
Exhaust Closes 11° After T.D.C.
Spark 37°±1° Before T.D.C.
Induction.
Power.
Compression.
Exhaust.
Direction of Rotation.
Inlet Closes 41½° After B.D.C.
Exhaust Opens 51° Before B.D.C.
B.D.C

Fig. 98.—Bottom Dead Centre.

remaining pressure in the cylinder would be of very little value. When the exhaust valve opens the burnt gases commence to leave the cylinder by their own pressure and so assist in scavenging the cylinder. The exhausting of the gases at this point also prevents a back pressure on the piston when the change of stroke occurs. The exhaust valve closes on, or just after, T.D.C.; in some cases the exhaust valve does not close until after the inlet valve opens. This overlap is very small but under these circumstances the momentum of the outgoing exhaust gases helps to create a suction on the inlet valve port. Owing to the time taken between the moment of ignition and the complete combustion of the gases, the ignition must take place before the piston has reached T.D.C. This position varies according to the design of the engine, and is mainly dependent on the speed of the piston. An average position is about 32° before

T.D.C.; this allows combustion to be complete by the time the piston is at T.D.C.

The cooling system.

421. The heat generated by the combustion of the gases is quite sufficient to make the cylinder walls red hot. The great heat would burn and dry up the lubricating oil, so the piston would not be able to slide up and down the cylinder and would seize. It is therefore necessary to cool the cylinder walls in order to keep them at a reasonable temperature. Two methods are in general use—air-cooling and water-cooling.

Air-cooling.

422. In air-cooling, the cylinder is generally provided with a series of cooling fins cast around it, and a current of air is forced past the fins, thereby carrying off the surplus heat conducted through the walls. Air-cooled cylinders of cast iron are being superseded by machined 40-ton nickel steel and aluminium alloys surrounding liners of steel or cast iron.

Water-cooling.

423. In water-cooling, the engine cylinder is surrounded by another chamber containing water, which is kept in constant circulation either mechanically or by use of the thermo syphon system, whereby as the water in the cylinder jacket becomes heated, it rises in virtue of its decreased density and the heavier cooler water takes its place. A radiator is necessary in this system, in order to dissipate the heat of the cooling water, so as to enable a given quantity to be constantly used. The temperature of the cooling water should be about 75° C. to 80° C.

MAGNETO IGNITION.

The magneto.

424. The magneto supplies a current of electricity which causes the gas between the plug points inside the cylinder of a petrol engine to become incandescent and thus ignite the charge. It should be noted, however, that there is no electricity in the magneto when the engine is stationary, but only magnetism. If a coil of copper wire with its ends joined be placed near the pole of a magnet and moved about so that a portion of the wire cuts across the lines of force surrounding the magnet the movement will cause a current of electricity to flow round the wire. If the ends of the wire be separated no current will be perceived (unless

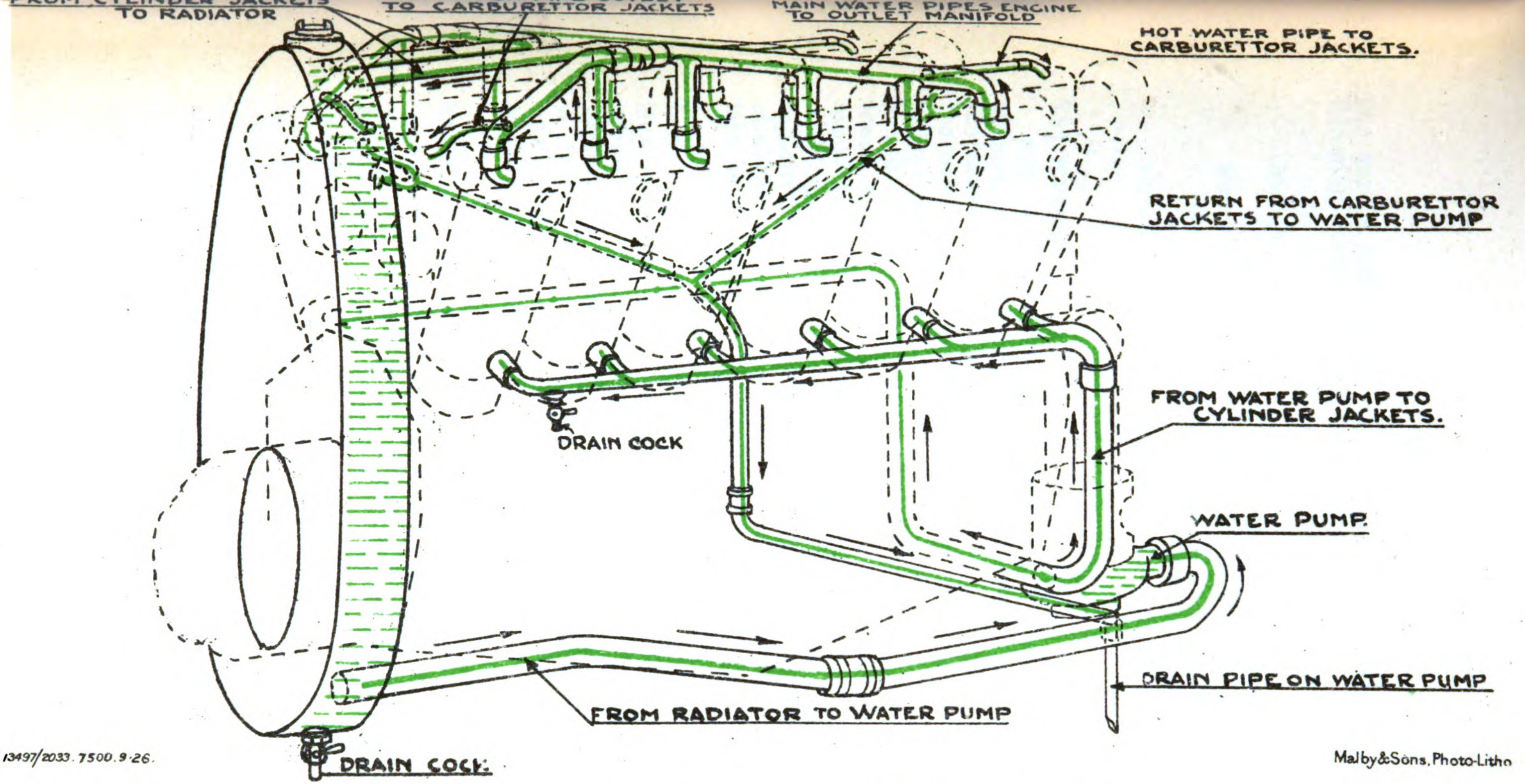

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FIG. 99. DIAGRAM OF WATER-COOLING SYSTEM.

the gap is very small). To obtain the best current the following conditions should be observed:—

(i) If possible the wire should cut the lines of force at right angles.

(ii) The wire should cut the lines of force at their strongest place—that is, near the pole of the magnet.

(iii) The wire should move as rapidly as possible.

(iv) The length of wire cutting the lines of force should be as long as possible.

The windings.

425. Instead of moving a wire near the pole of a bar magnet, a much better effect can be obtained by bending the magnet in the shape of a horse-shoe and then moving the wire between the two poles. The most convenient way of moving the wire is to rotate it. For this reason a certain length of thick wire, called the primary winding, is wound round and round a piece of soft iron. This is called an armature. The armature is revolved at a high speed, thereby enabling the wire to cut the magnetic lines of force with great rapidity, which gives rise to an electric current. With this revolving armature the current is reversed every half revolution as it passes the opposite poles of the magnet.

426. As the current of electricity that can be obtained from a single coil of wire on an armature possesses only a small pressure or tension, it cannot overcome any great resistance. A much greater pressure can be obtained by the use of a second coil of wire. This second coil of wire is called the secondary winding, and consists of a large number of turns of fine wire and is often fifty times as long as the primary winding.

Secondary currents.

427. If two coils of wire, called P and S (fig. 100), be placed close together, and a current of electricity is passed through P, no effect will be apparent in the circuit S while the current in P is steady.

If, however, the current in P suddenly ceases, a high tension current will be generated in S if the circuit is complete. Although there is no electrical contact between the two circuits, there is an essential link between one circuit and the other in the presence of the magnetism that is generated in the primary circuit. It has been explained that passing a coil near a magnet causes electricity to be generated, and it should seem reasonable to suppose that causing electricity to flow in a coil will, conversely, be the

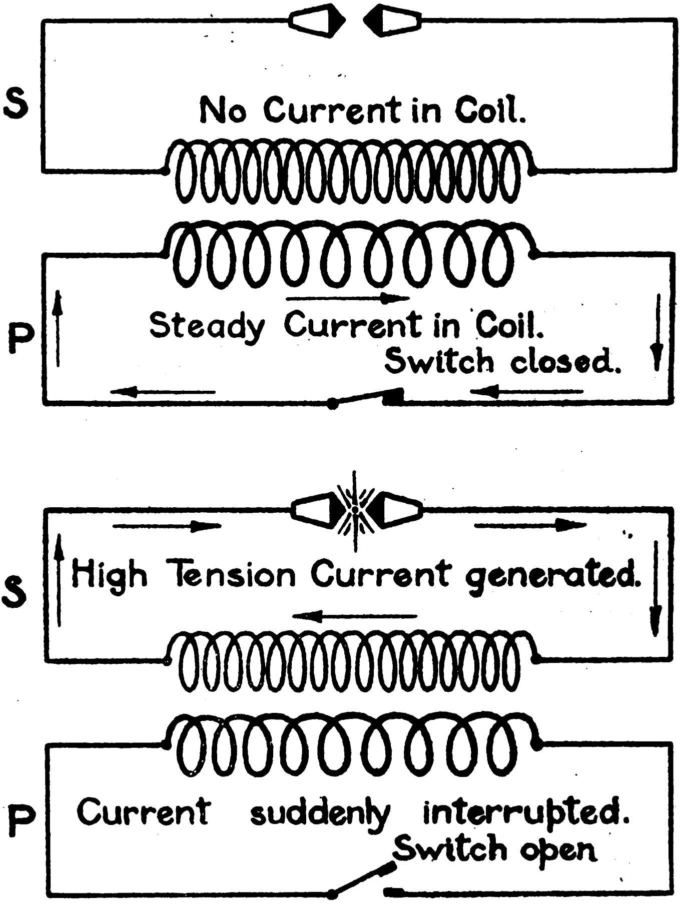


Fig. 100.

means of generating magnetism. The magnetic lines of force generated by an electric current are concentric with the wire and when the current ceases to flow the lines of force cut the secondary winding and generate electricity. This is called induction. If the secondary winding has fifty times the number of turns as the primary winding, the secondary current will have fifty times the electric pressure, which is called voltage, but will only have one-fiftieth of the amount of current, which is called amperage. Should there be a small gap in the coil S, then, owing to the high pressure of the electricity in the secondary winding, a spark will take place between the points of the gap.

The contact-breaker.

428. In order to be able to stop and start the current in the primary circuit, a piece of mechanism, known as the contact-breaker, is fitted to one end of the armature.

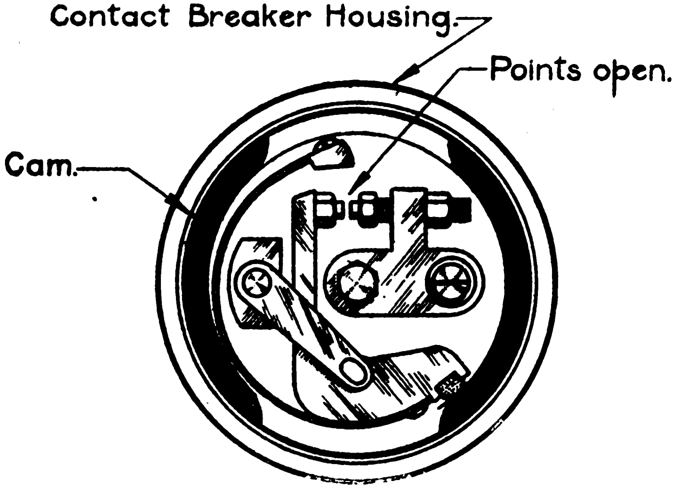


FIG. 101.—**Make and Break.**

In most makes the contact-breaker is keyed to one end of the armature spindle and rotates with it. It carries a rocking lever which can move or rock in such a manner that it either joins up or separates two points. When the two points are together the low tension current is free to flow, and when they are separated the circuit is broken and the current cannot flow. The strongest secondary current will be obtained when the primary current is strongest. Since there is a reversal of the flow there must be a moment when there is no current at all, and for the same reason there must be a point when the impulse is at its maximum. Owing to the magnetic drag—that is, the lines of force being dragged round with the armature—the real maximum position is when the armature has rotated somewhat farther than the vertical position. At this point the contact-breaker is adjusted to break the circuit.

The condenser.

429. When the points of the contact-breaker are separated there is a tendency for the current to continue to flow in the form of a spark across the break. This would soon burn the points and cause misfiring. To overcome this difficulty a condenser is fitted. This consists of many sheets of tinfoil separated from each other by a non-conductor

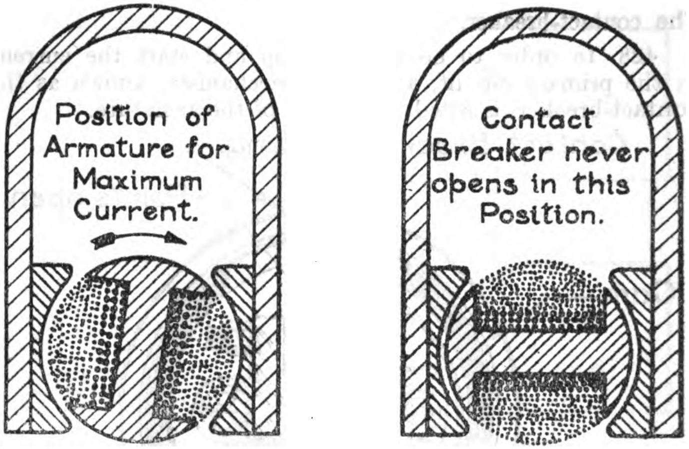

Position of Armature for Maximum Current.
Contact Breaker never opens in this Position.

FIG. 102.

of electricity such as mica. Alternate sheets of this tinfoil are connected to the primary winding, whilst the intermediate sheets are connected to earth.

Collecting the high tension current.

430. The high tension current has to be collected from the revolving armature and delivered to a stationary wire leading to the sparking plug. For this purpose a brass ring is mounted at one end of the armature. This brass ring is usually called the collector ring. A small pencil of stationary carbon is kept pressing on this ring by means of a spring, thus allowing the current to pass from the ring through the carbon brush to the distributor.

Distributing the high-tension current.

431. In a multi-cylinder engine the secondary current has to feed each separate sparking plug. This is done by means of a distributor. The high-tension current is led from the collector ring to a carbon brush or pencil, which, in a four-cylinder engine, is made to revolve at the same speed as the camshaft—that is, half the speed of the engine. This brush as it revolves comes into contact with metal segments let into an insulated plate. There is a metal segment for every cylinder of the engine, and electricity is conducted from the metal segments to the sparking plugs by means of high-tension wire.

The safety spark gap.

432. Should the points of the sparking plug be very far apart, the current will be unable to spark across, and it will

travel back to the magneto through the safety spark gap. If this emergency circuit were not provided, great damage would be done to the armature windings. The safety spark gap consists of two metal points with a gap between them. One point is connected to the high-tension circuit at a point between the armature and the distributor and the other to the framework of the magneto. These points are placed much farther apart than those of the sparking plug. The high-tension current will jump a wider gap outside the engine than inside, owing to the additional resistance inside due to the compression of the gas in the cylinder.

The magneto switch.

433. If the low-tension current is conducted back to the frame of the magneto instead of being allowed to pass through the contact breaker, it will prevent the generation of the high-tension current. To switch off a magneto it is only necessary to earth the low-tension current. Thus, when the magneto is switched off, the current is really switched on to the earth.

The sparking plug.

434. The high-tension current passes through the centre of the plug by means of a thin metal rod, which is surrounded by a non-conductor, such as porcelain or mica. The non-conductor is fixed to an outer metal shell which screws into the cylinder. The gap is formed between the inner central rod and a part of the outer shell. The current jumps from the inner rod to the outer shell and then passes through the engine back to the magneto.

Advance and retard.

435. As the complete combustion of the gases does not take place simultaneously with the spark, it is necessary to alter the position of the spark in accordance with the speed of the piston. When the engine is running slowly, the spark may be timed to take place when the piston has reached the top of the compression stroke. If the engine is running fast, the piston will have covered a greater distance in the same time, which necessitates the timing of the spark to take place before the piston has reached the top of the compression stroke. The time of the ignition can be varied by altering the position of the cam that operates the contact breaker. This cam is fitted to a housing which can be given a small rotary movement (fig. 104).

The contact breaker, in fig. 104, is rotating in a clockwise direction. The left-hand sketch shows the housing in the position of full retard. In the right-hand sketch the housing

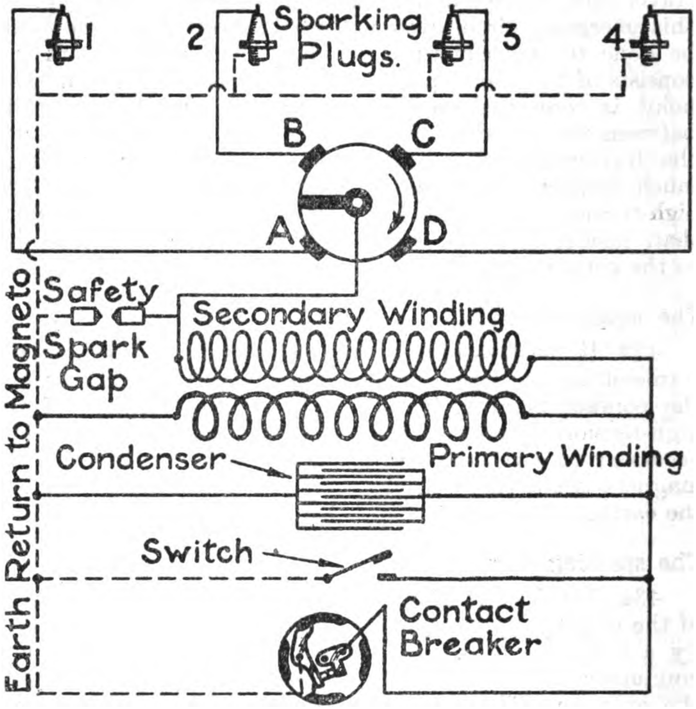
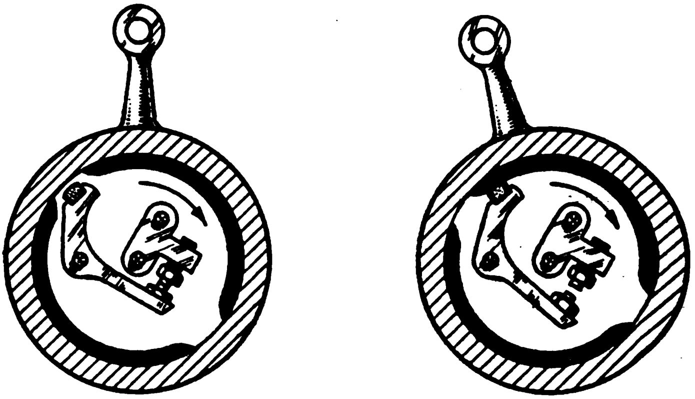


FIG. 103.—Magneto Wiring Diagram.



Ignition Retarded.

Ignition Advanced.

FIG. 104.

has been moved in an anti-clockwise direction, and is at full advance.

Internal timing of a magneto.

436. Whenever the points of the contact breaker separate, a high-tension current is generated in the secondary winding, and at this moment it is necessary that the brush of the distributor should be in contact with one of the metal segments of the distributor plate. This can be obtained by accurately engaging the gear wheels between the armature and the distributor. The exact position of the carbon brush on the metal segment depends upon the position of the contact breaker housing, whether it is advanced or retarded. When the ignition is fully advanced, the distributor brush should be at the beginning of the metal segment.

THE DELCO IGNITION SYSTEM.

General remarks.

437. This system is used on the Liberty engine. It is not possible to fit an ordinary magneto, as the cylinders are at 45° and the crank angles at 120°. This means that the firing points between cylinders are 45° and 75°. A magneto reaches its maximum strength every 180°, and therefore whatever gearing is used the firing angles must be divisible into 180°.

438. A dynamo generator is gear-driven from the engine. In circuit with this is an accumulator battery, which is charged by the generator. The current is supplied to two ignition units on the ends of the two camshafts. A voltage regulator is fitted to control the output. Induction coils, contact breakers, condensers, distributors, and a special switch are used in a similar manner to those in a magneto (fig. 106).

The generator.

439. This is a totally enclosed 4-pole shunt-wound dynamo, generating 15 amps at 10 volts, the normal output being about 5 amps. The armature is of the usual laminated type.

The battery.

440. This consists of four Exide or Willards cells in an ebonite case, and generates 10 volts.

Voltage regulator.

441. This consists of a soft iron core wound with three windings of different kinds. Magnetisation of the core pulls down a blade and so breaks the direct path to earth of the field current. When the voltage is below that at which the regulator is set, the points are closed and the current passes to earth. When the voltage rises the points open and the current passes through the two coils, one of large resistance

and the other wound non-inductively. A resistance is therefore put in the field and a fall of current follows (figs. 105 and 106).

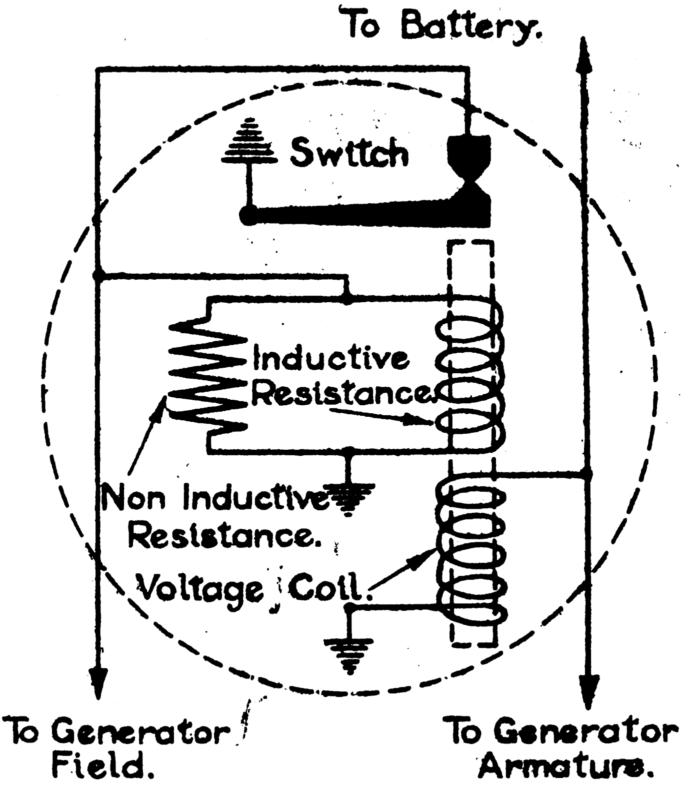


FIG. 105.—Voltage Regulator.

442. At starting, the current is supplied by the battery with only one switch on. As soon as the engine revolutions exceed 650 r.p.m. the generator can be made to take up the ignition by putting on the other switch, and by further increasing the speed will commence to charge the accumulator. Should the battery break down, the generator will supply the current, but the engine cannot be started on the generator. If the generator breaks down the engine can be run on the battery for a safe period of one hour, provided that one switch only is left on.

CARBURETTORS.

General remarks.

443. The process of mixing petrol vapour with air is called carburation, and the apparatus that accomplishes

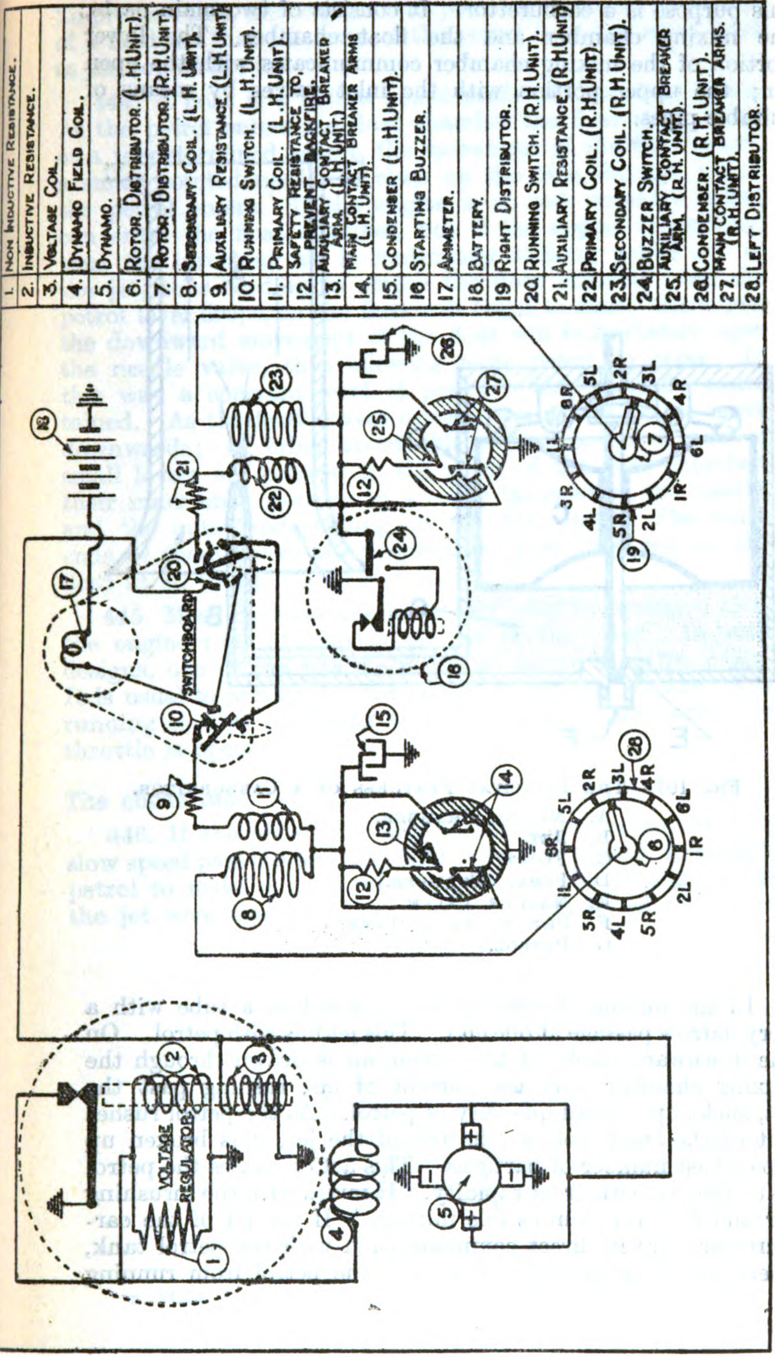

1. Non Inductive Resistance.
2. Inductive Resistance.
3. Voltage Coil.
4. Dynamo Field Coil.
5. Dynamo.
6. Rotor, Distributor. (L.H.Unit).
7. Rotor, Distributor. (R.H.Unit).
8. Secondary Coil. (L.H. Unit).
9. Auxiliary Resistance. (L.H.Unit).
10. Running Switch. (L.H.Unit).
11. Primary Coil. (L.H.Unit).
12. Safety Resistance to Prevent Backfire.
13. Auxiliary Contact Breaker Arm. (L.H.Unit).
14. Main Contact Breaker Arms (L.H.Unit).
15. Condenser (L.H.Unit).
16 Starting Buzzer.
17. Ammeter.
18. Battery.
19. Right Distributor.
20. Running Switch. (R.H.Unit).
21. Auxiliary Resistance. (R.H.Unit).
22. Primary Coil. (R.H.Unit).
23. Secondary Coil. (R.H.Unit).
24. Buzzer Switch. (R.H.Unit).
25. Auxiliary Contact Breaker Arm. (R.H.Unit).
26. Condenser. (R.H.Unit).
27. Main Contact Breaker Arms. (R.H.Unit).
28. Left Distributor.
Switchboard
Voltage Regulator
5L 2R 3L 4R 6L 1R 2L 5R 4L 3R 1L 6R
+ − + −

Fig. 106.—Delco Ignition System—Diagram of Electrical Connections.

this purpose is a carburettor. It consists of two main parts, the mixing chamber and the float chamber. The lower portion of the mixing chamber communicates with the open air; the upper portion with the inlet valves by means of suitable pipes.

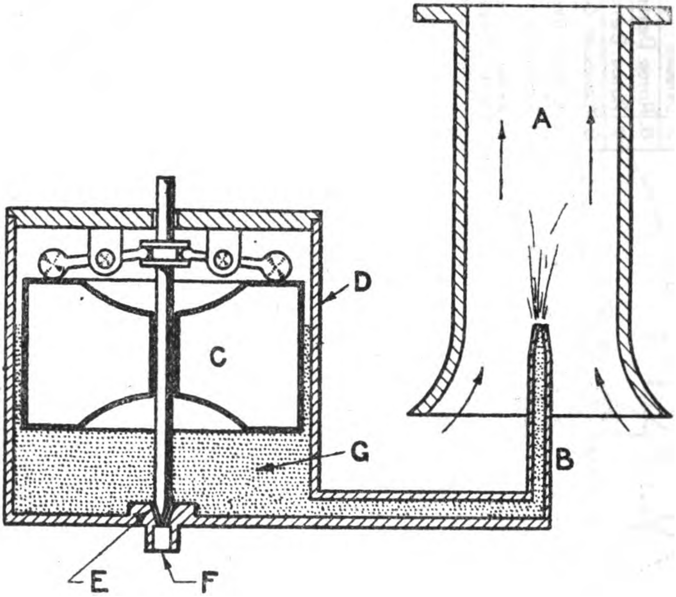


Fig. 107.—The Principal Features of a Carburettor.

A. Mixing Chamber.
B. Jet.
C. Float.
D. Float Chamber.
E. Needle Valve.
F. Petrol from Tank.
G. Petrol.

In the mixing chamber is a jet, which is a tube with a very narrow passage at one end. This jet fills with petrol. On the downward stroke of the piston, air is drawn through the mixing chamber, and the current of air, rushing past the jet, sucks up a small quantity of petrol. As the petrol rushes out of the small hole at the top of the jet, it is broken up into a vast number of particles. This action causes the petrol to evaporate with great rapidity. It mixes with the inrushing air and forms a combustible mixture. If the jet of the carburettor were in direct communication with the petrol tank, there would be nothing to prevent the petrol from running out of the small hole at the top of the jet and overflowing. To prevent this, the height of the petrol is regulated by means of a float, so that the level of the petrol is at the same level as the top of the jet.

444. A float is a hollow vessel made of thin sheet brass. As the petrol enters the float chamber the float rises, until, at a predetermined height, the movement of the float causes a small pointed needle to close up the hole through which the petrol enters. If the engine is at rest no more petrol can enter the float chamber, but if the engine is running, then the inrushing air is continually sucking petrol out of the jet, thus tending to empty the float chamber. As the petrol level drops, so the float will begin to sink; thereupon the downward movement of the float will immediately open the needle valve, thus allowing more petrol to enter. In this way a constant level of petrol is automatically maintained. As the float moves upward the needle has to move downwards; to bring about this reverse action a pair of small levers are pivoted to the cover of the float chamber, their inner ends working in a collar fastened to the needle, and the outer ends resting on the float itself. The outer ends of these levers are weighted, so that they rest on the float at all times.

445. Most carburettors have two jets, so arranged that the engine runs exclusively on one or the other. In such designs, one of the jets is, of course, larger than the other. It is usual to arrange for the engine to use one jet when it is running slowly, and bring the other jet into use when the throttle is opened.

The choke tube.

446. If the air on its way to the cylinders moves at a slow speed past the jet, it would not be able to suck up enough petrol to make a good mixture. But if the passage round the jet were made smaller, the same quantity of air to get

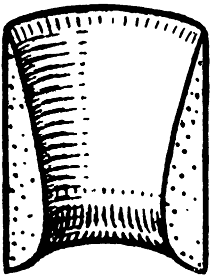


FIG. 108.—Choke Tube.

past in the same time would have to move faster. The increased speed of the air would create a better suction and draw more petrol out of the jet. This result can be obtained by fitting a choke tube, which reduces the area of the passage surrounding the jet.

The throttle.

447. It is necessary to be able to regulate the flow of gas as it leaves the carburettor. For this purpose a throttle is fitted. This usually consists of a rotating barrel fitted in the top of the carburettor. This barrel has a hole bored through the middle, so that when the throttle is open this hole is the same size and in line with the induction pipe. When turned at 90°, the induction pipe is shut off from the carburettor.

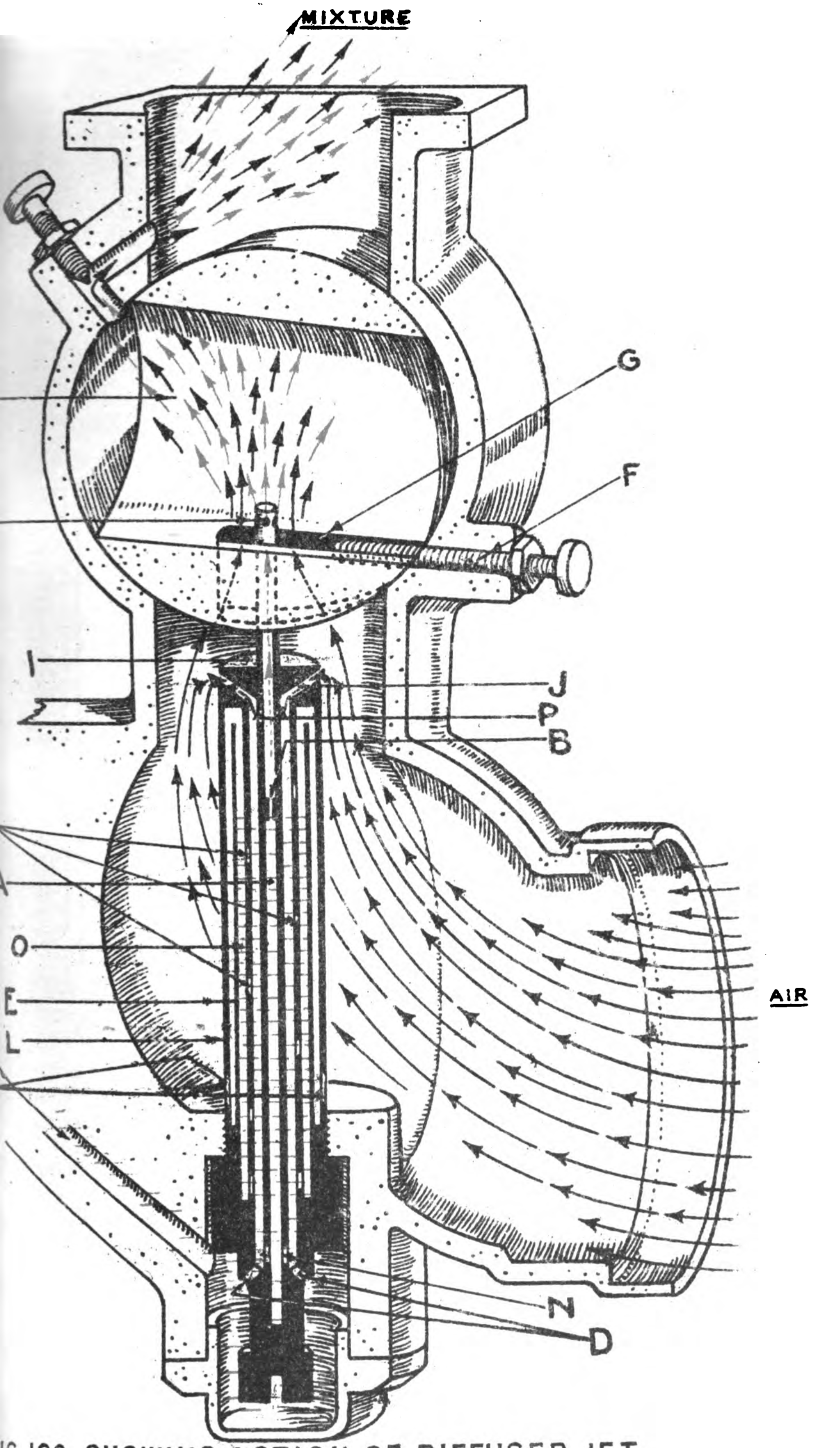
Claudel Hobson carburettor.

448. This is of the usual float type. The float chamber cap on a C.H. carburettor screws down on a fibre washer and should be air-tight. This carburettor is fitted with a special jet, called a diffuser jet. The object of this jet is to keep approximately correct ratio of air and petrol at all engine speeds. The pilot or slow-running jet is fitted in the centre of the diffuser jet and protrudes into the throttle barrel (*see* fig. 109).

The diffuser.

449.—(i) The diffuser type of jet. fitted to all models of Claudel-Hobson carburettors, is identical in its principles of operation, though its construction varies slightly in the R.R.C.H. Figs. 110 and 111 show various parts of the jet. The construction of this component is designed to solve two problems in carburation. In the first place, the crude type of carburettor delivers a stream of petrol and a stream of air just below the level of the throttle valve; the resulting mixture is "lumpy" and "wet"; the petrol cannot become efficiently atomised, and as a consequence the air is not perfectly impregnated with petrol. The diffuser type of jet commences to atomise the petrol and to form an emulsion of petrol spray and air before the mixture, delivered from the emulsion head, passes in to the main stream of air which is passing up the choke tube to dilute it. By this means a comparatively homogeneous mixture is assured.

(ii) In the second place, the crude type of carburettor fails to supply a uniform mixture throughout varying engine speeds. As the engine speed falls, the depression in the choke tube becomes less and the pressure difference between the float chamber and the top of the jet approaches nearer to



IG.109. SHOWING ACTION OF DIFFUSER JET.

Malby&Sc

zero. The former ratio of petrol to air, however, under the lower depression does not remain constant, the quantity of petrol being less in proportion to the quantity of air. A weak mixture naturally results. This also applies conversely, since when the engine speed is increased the proportion of petrol drawn off becomes greater than that of the air and too rich a mixture results. These conditions are brought about by reason of the fact that the inertia of the petrol is greater than that of the air, and, both being subjected to a pulsating flow, the more rapid the pulsations (as the engine speed increases), the greater the effect on the more inert component of the mixture, *viz.*, the petrol. The diffuser jet is designed to meet this difficulty.

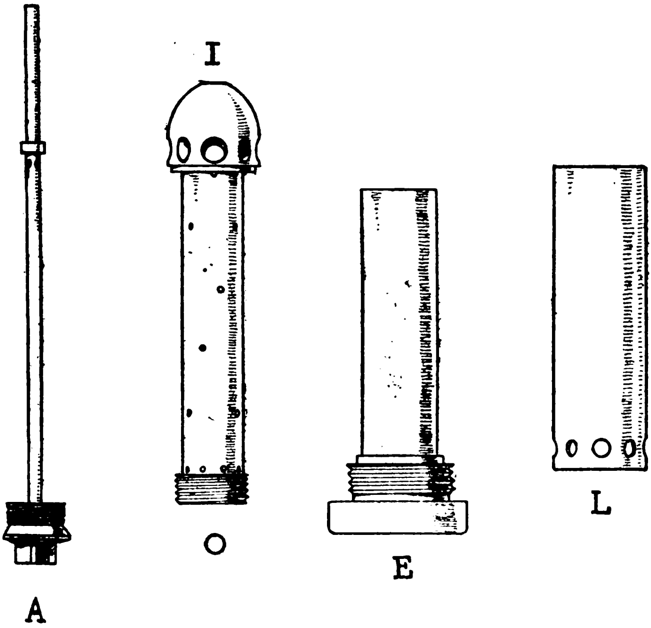


Fig. 110.—Diffuser Dismantled.

Components of diffuser.

450. The jet assembly comprises four concentric tubes, *viz.* :—

(i) *The Pilot Jet* (A) (figs. 110 and 111), or central tube, is of small diameter, and is fixed in the centre of the main jet (D) (fig. 111) of the carburettor. The main jet of the carburettor screws into the main base plug of the diffuser assembly, which in turn is screwed into the boss formed in the structure of the carburettor. The pilot jet tube is appre-

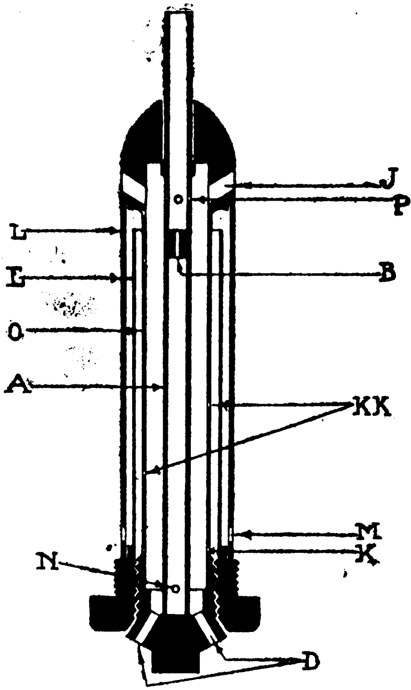


FIG. 111.—Section of Diffuser.

ciably longer than the other tubes, and projects into the slot cut in the lower edge of the barrel throttle. This provides that when the throttle is in the slow-running position only this jet is subjected to the depression that is present inside the throttle chamber; the other tubes are shut off by the closing of the main gas passage. A constriction or neck formed towards its upper end constitutes the actual slow-running orifice and governs the quantity of petrol admitted to the engine at low speeds. Four small holes (P) drilled radially in the tube, coincident with the holes in the emulsion head, admit air, whilst petrol is supplied through the four holes (N) drilled at the base of the tube.

(ii) *The emulsion tube* (O) terminates immediately below the throttle barrel. It is threaded at the lower end and is screwed into the upper part of the same thread in the main base plug which houses the main jet, where it is secured by being expanded at its lower end. A row of holes is drilled round its base, and it is also freely drilled at regular intervals from top to bottom. The upper end terminates in the emulsion head (I), which consists of a dome drilled radially with eight holes (J) inclined upwards from the centre. A small hole, ·75 mm. in diameter, located immediately below the emulsion head, is designed to prevent flooding at the diffuser. This is brought about by a syphoning action set up between the guard tube and the air tube, which causes the petrol to flow over the lip of the guard tube whenever the level rises as high as the top of it. Flooding frequently occurs when the throttle is closed suddenly, which produces a rush of petrol into the diffuser. Once established, the flow continues, though the level may have sunk to the normal height; the small hole serves to break this flow.

(iii) The *guard tube* (E) surrounds the diffuser tube, but terminates just short of the emulsion head, thereby providing a free downward passage for the air over its lip.

(iv) The *air tube* (L) is the outer tube of the assembly, and is located between the emulsion head (I) and the main base plug when the emulsion tube is screwed into position. Large air holes (M) freely drilled round its base admit air to the space between the emulsion tube and the guard tube by way of the passage left between the lip of the latter and the emulsion head.

(v) The *main jet* (D), which forms the base of the pilot jet tube, is drilled either with one or two calibrated holes (D) (according to calibration) which constitute the main jet orifice. The base of the jet is submerged in the petrol in the well formed below it, to which petrol is supplied from the float chamber. The petrol enters the jet orifices (D) and rises, filling the pilot jet tube and emulsion tube, and, passing through the holes drilled in the emulsion tube, it rises within the guard tube until it reaches the level of the petrol in the float chamber. Regarding the float chamber and jet assembly as the two arms of a U-tube, respectively, it will be seen that the guard tube actually forms the opposite arm of the U to the float chamber, and accordingly the petrol level is set in relation to the top of this tube. In practice, the setting comes at about 8 mm. below the top.

Action of the diffuser.

451. Figs. 109 and 111 indicate respectively the action of the diffuser at closed and at full throttle.

(i) The conditions when the engine is not running are as follow :—Petrol enters by the main jet (D) (figs. 109 and 111) and rises within the guard tube (E) until checked by the action of the float and needle valve. All the holes (K) in the emulsion tube are covered.

(ii) When the engine is started with the throttle in slow-running position (fig. 109), only the pilot jet (A) is subjected to the depression in the throttle chamber (H), since the gas passage is closed except for the slot (G) cut in the lower edge of the barrel throttle. The effective area of this slot is regulated by a screw (F), entering from the outside of the carburettor casing and projecting into the slot. By screwing this in or out of the slot, the choking effect of the air passing the top of the pilot jet may be adjusted to draw off a mixture of correct strength.

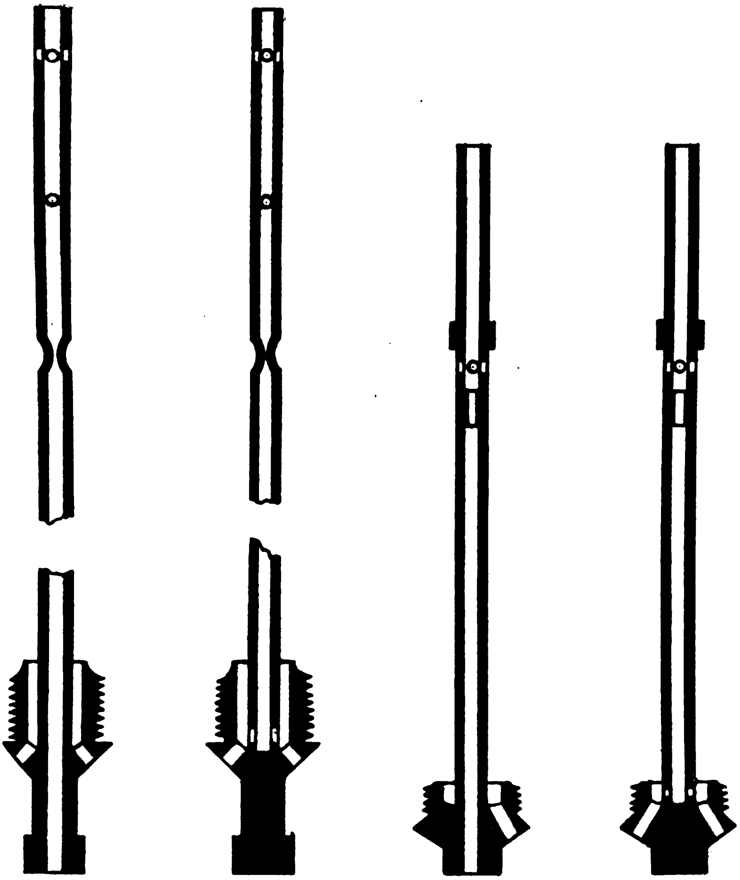
(iii) When the throttle is partially opened, there is a depression in the region of the emulsion head, which is located at the neck of the fixed choke tube formed in the body casting. The depression created at the holes in the emulsion head causes the air to enter in the holes (J) in the air tube, and, passing over the lip of the guard tube (E) and through the upper holes (K) in the emulsion tube, it carries up the petrol surrounding these holes. As the depression at the emulsion head increases, the inrush of air over the lip of the guard tube (E) on the petrol contained within the guard tube increases also, and uncovers more of the holes in the emulsion tube. The proportion of petrol to air in the resultant mixture which is drawn upwards through the emulsion head is decreased, for since more of the holes in the emulsion tube are uncovered, more air is admitted. This approaches the required conditions.

(iv) The main jet is calibrated so that it will pass the requisite amount of petrol for sustained running at full throttle. When the engine is running under these conditions, therefore, no petrol has time to accumulate in the guard tube, and the emulsion tube constitutes a "straight through" passage up which the petrol passes, mixing on its way with the air which enters by the holes. When the engine is throttled down, more petrol passes through the main jet than the slow-running jet can utilise; this accumulates in the tubes and forms a reserve in readiness for the coming acceleration of the engine.

The altitude control.

452. The type of altitude control fitted to H.C. 7 and H.C. 8 models is known as the vacuum control. The type fitted to the R.R.C.H. differs considerably from this.

(i) *Vacuum control.*—At the altitudes reached by modern aeroplanes, the density of the atmosphere decreases so appreciably as to exert a very marked influence upon carburation. For example, if a carburettor is set to supply an engine with correct mixture at ground level, this mixture will be incorrect at a height of 10,000 ft., as the density of the air at that altitude is approximately thirty per cent. less than at ground level. Various methods of correcting the mixture for altitude are technically possible. The system at present described



1 Parallel. 2 Series. 3 Parallel. 4 Series.

Fig. 112.—Sections of “ Series ” and “ Parallel ” Slow-running Jet Tubes.

provides a means of reducing the petrol supply to counterbalance the reduced density of the air. As previously stated, the action of a float chamber and jet is based upon the principle of a U-tube, one arm of the U corresponding to the column of petrol in the jet and the other to that in the float chamber. The petrol feed is produced by there being an atmospheric pressure of about 14·7 lb. to the sq. in. on the float chamber column, and a reduced pressure caused by the action of the choke tube on the jet column when the engine is running. By the vacuum system of altitude control, the atmospheric pressure on the float chamber column of the U can be weakened as the higher altitudes are reached. When this is done, the pressure on the two columns of the U is more closely balanced and the volume of the petrol supply is proportionately reduced. The depression in the choke tube is utilised to reduce the atmospheric pressure on the float chamber by bringing the two into communication with each other. The necessary fittings are as follow :—

(*a*) The float chamber must be air-tight, so that atmospheric pressure can be partially shut off from it when the aeroplane is flying at considerable altitudes.

(*b*) A restricted duct or air-leak hole must be fitted, through which air at atmospheric pressure can be admitted to the float chamber when the engine is running at ground level.

(*c*) A controllable duct must be provided, through which the depression in the choke tube can be communicated to the float chamber when the aeroplane is flying at a considerable altitude.

(*d*) As a modern aeroplane has a range from ground level to over 20,000 ft., the precise amount of correction required will vary considerably. It is desirable that the two ducts specified in (*b*) and (*c*) above should be interconnected so that the float chamber pressure may be compounded of (1) atmospheric pressure, (2) atmospheric pressure and a controlled proportion of the depression present in the choke tube.

(ii) *Petrol regulation valve (R.R.C.H.)*—

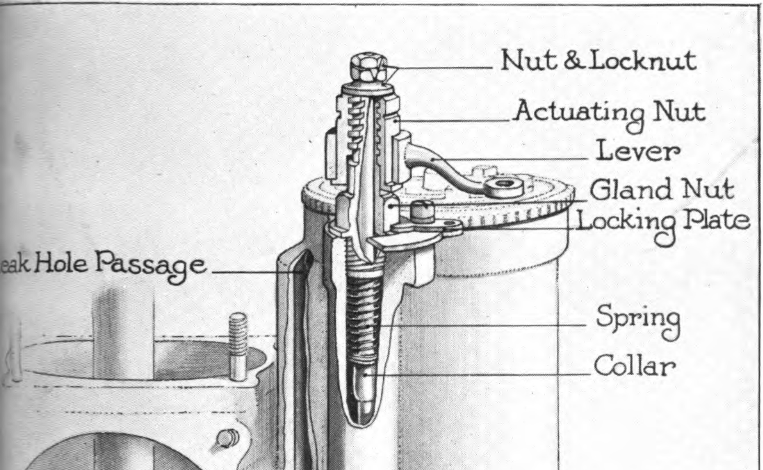
The action of this type of altitude control differs from the vacuum control in that the necessary reduction of the quantity of petrol supplied to the engine at a high altitude is controlled mechanically by the operation of a needle valve, instead of being governed by the depression in the choke tube. Beside serving to reduce the petrol supply at high altitudes, this valve controls the quantity of petrol that enters the diffuser instead of the main jet, and virtually constitutes a variable jet. The plug at the base of the diffuser, known as the main jet, is provided with four large holes and, therefore, no longer acts as a jet (fig. 113).

LUBRICATION.

General remarks.

453. Rubbing two surfaces together causes friction; and friction produces heat. If a dry shaft revolves inside a plain bearing, the rubbing action between the two metal surfaces would produce so great a heat that in a short time the metal of the bearings would melt, and the shaft would seize. To prevent excessive heat there should be no actual contact

[*To face page* 198.



IG. 113.—Perspective View of Altitude Control Mechanism (or Petrol Regulating Valve) and Pressure Balance Passage on R.R.C.H. Type.

between the shaft and its bearing. This can be done by introducing a thin film of lubricating oil between the two surfaces. To ensure the presence of this film of lubricant the oil is usually forced into the bearing under pressure. A lubricant must possess the property of viscosity, that is, the separate molecules attempt to stick together, and the oil is therefore reluctant to change its shape. The viscosity of oil becomes less as its temperature rises.

454. Aero engines of the present type are lubricated by the pressure-fed dry sump system, that is, the oil is forced into the necessary parts of the engine by means of a pump, and after being in use falls to the bottom of the crankcase, where it is drawn off by a pump (usually called the scavenger pump) and returned to the oil tank. This keeps the sump comparatively free from oil. The scavenger pump is of larger capacity than the pressure pump. This is to make sure that the sump is kept dry under varying conditions, such as a long dive in an aeroplane, when all the oil that falls in the sump runs to the forward part of the engine and collects there. The scavenger pump takes the oil away when the aeroplane is manœuvred to an even keel and the oil flows to its normal place in the bottom of the sump.

Oil pumps.

455. These are usually of the spur gear type. The spur wheels revolve in a casing and the oil is carried round by the teeth as shown in fig. 114. The clearance between the teeth of the spur wheels and the casing of the pump should not exceed the small limits laid down for any particular engine.

Oil pressure relief valve.

456. The maximum and minimum oil pressures which are specified by the manufacturers must be adhered to. This oil pressure is controlled by a relief valve which is fitted on the delivery side of the pressure pump. This relief valve is usually of the spring-loaded poppet type, the tension of the spring being adjusted until the correct oil pressure is obtained. The excess oil is returned direct to the crankcase and taken away by the scavenger pump.

A general system of lubrication.

457. Oil is fed from the tank by means of a pipe to the pressure pump, where it passes through a filter before it is forced past the oil pressure relief valve. From this point it is forced along a duct or pipe in the crankcase. Branches lead from this duct to each of the main bearings. The oil lubricates the main bearings and then passes through a small hole in the journal to the inside of the crankshaft. The crank-

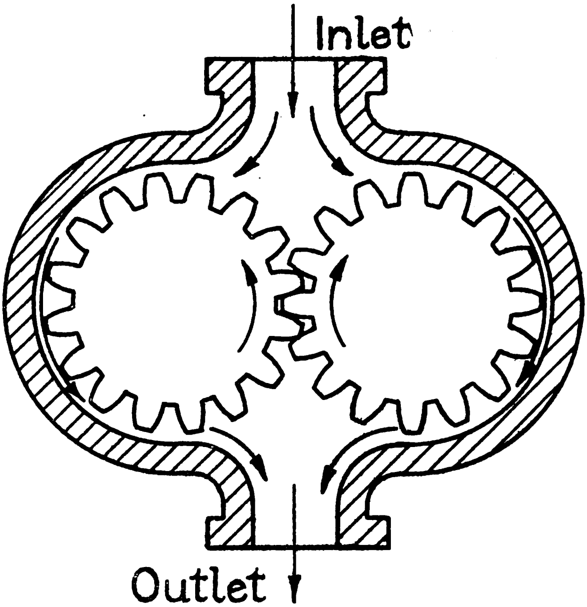


FIG. 114.—Oil Pump.

shaft in this way becomes filled with oil. The oil leaves the shaft through a small hole in the connecting rod big end journal, and so lubricates the big end bearing. In some engines the oil is then led by a small pipe attached to the connecting rods to the gudgeon pins. In others, the gudgeon pins and cylinder walls are lubricated by oil which is splashed up from the crankcase by the crankshaft.

458. The camshaft is usually oiled by a separate system, sometimes at the same pressure as the crankshaft and sometimes at a lower pressure. The oil is led to the inside of the hollow camshaft and passes through small holes drilled in the camshaft to the bearings. The oil passes through the bearings and falls into the camshaft casing, where it lubricates the cams and rocker arm bearings. The surplus oil passes along the camshaft casing down the camshaft driving shafts and into the crankcase. As the oil is returned to the crankcase it is sucked through a filter by the scavenger pump and returned to the tank.

ENGINE POWER.

The power of an engine.

459.—(i) *Power* is the time rate of expending energy in doing work.

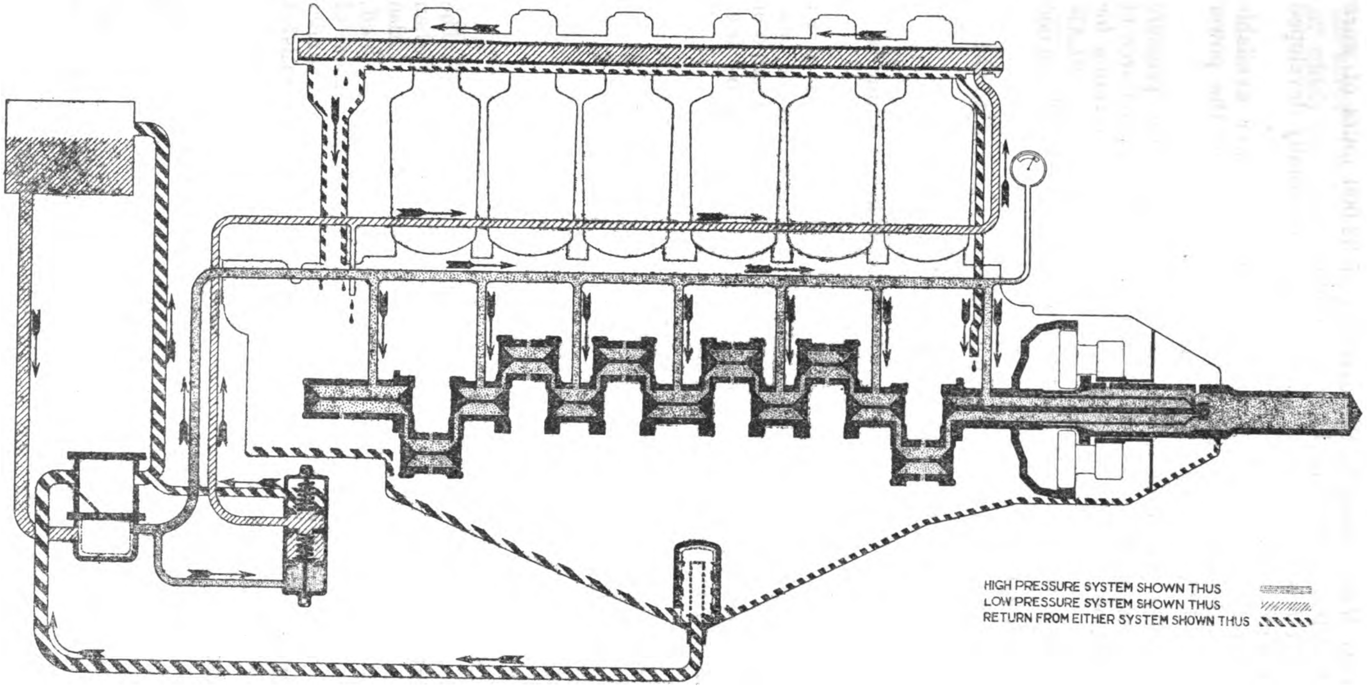

HIGH PRESSURE SYSTEM SHOWN THUS ▨
LOW PRESSURE SYSTEM SHOWN THUS ▨
RETURN FROM EITHER SYSTEM SHOWN THUS ▨

Fig. 115.—Rolls-Royce Lubrication System.

(ii) *Horse power* is the exertion of 33,000 units of work or foot-lbs. in the period of one minute.

(iii) *Indicated horse power* is the power actually developed in the cylinder.

(iv) *Brake horse power* is the effective power available after deducting from the indicated horse power the power absorbed by the engine friction.

(i) The power of the engine depends upon the pressure of the expanding gases, the length of the stroke, the area of the piston, and the number of explosions. The formula for obtaining the indicated horse power from this data is $\frac{PLAN}{33,000}$ for each cylinder—

where P = mean effective pressure in lbs. to the square inch.
L = length of stroke in feet.
A = area of piston in inches.
N = number of power strokes in a minute.
33,000 ft.-lbs. = 1 horse-power.

(iv) The brake horse power is found by means of an absorption or transmission dynamometer. It may be conveniently ascertained by the electrical output of a dynamo of known efficiency. To ascertain brake horse-power by friction dynamometer, the formula is as follows :—

$$B.H.P. = \frac{WL2\,R}{33,000}$$

Where W = weight in lbs.
L = leverage in feet.
R = revolutions in one minute.
33,000 ft.-lbs. = 1 horse-power.

Thermodynamics of the petrol engine.

460. The petrol engine is simply a heat engine. The mixture in a petrol engine will behave, up to the time when the piston reaches top dead centre, as if it were air. Also the products of combustion, after the burning is completed, have physical properties differing only slightly from those of air, and consequently the working substance in the cylinder may, without serious error, be treated as though it consisted entirely of air.

Indicators.

461. The engine indicator consists of (i) a drum carrying a sheet of paper which, by the rotation of the drum, is moved a certain distance proportional to the travel of the piston, (ii) an arm, the motion of which is governed by the pressure in the cylinder, carries on its end a pencil, which traces on

the sheet of paper a diagram, the vertical values or ordinates of which are proportional at every point during the travel of the piston to the pressures inside the cylinder. James Watt was the first to appreciate the need of accurate knowledge of the action taking place in a cylinder.

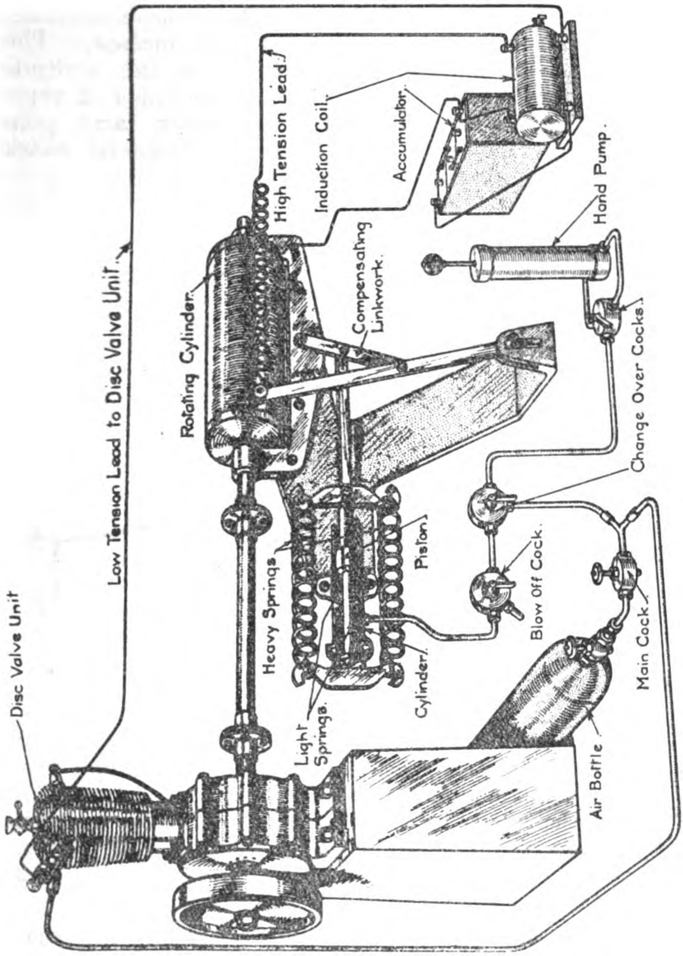


FIG. 116.—DIAGRAMMATIC SKETCH OF "FARNBORO" INDICATOR ON SINGLE-CYLINDER ENGINE.

The indicator diagram (ideal).

462. The ideal diagram obtained from a four-stroke cycle is shown in fig. 117. The horizontal line AC, called the abscissa, represents the length of the stroke. The vertical line AB, called the ordinate, represents the highest pressure,

Vertical distances along the line AB represent pressures into the square inch absolute, while horizontal distances measured along AC represent distances travelled by the piston, or, as the cross section of the cylinder is constant, these distances may also represent cylinder volumes in cubic inches. Thus point 4 represents 350 lbs. a square inch in the cylinder when the volume in the cylinder is V. As the line 1–2 represents the entire distance travelled by the piston, any point "d" on AC represents a certain cylinder volume or marks the position of the piston at that part of the stroke.

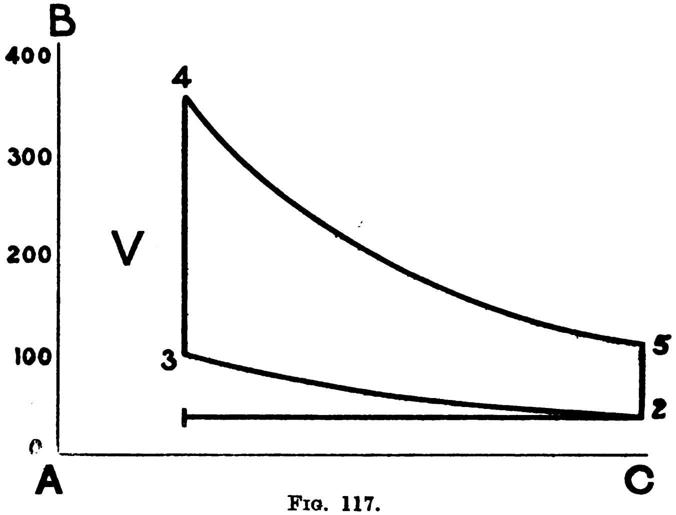


FIG. 117.

(i) *Stroke one.*—The piston is at the end of its stroke at point 1. The clearance space V is full of the residual products of combustion, the pressure is atmospheric (about 14·7 lbs. to the square inch), and the exhaust valve has just closed. As the piston makes its stroke, the inlet valve opens, admitting the charge at atmospheric pressure. Point 2 represents the position at the end of this stroke.

(ii) *Stroke two.*—The inlet valve now closes and the compression stroke commences, increasing the pressure. This is represented by the line 2–3, which shows the rise in pressure. At point 3 the volume is again V. It is assumed that during this stroke the gas retains all the heat formed through compression and receives none from outside. This is called adiabatic compression. When the charge has reached this condition it is fired and the heat generated raises the temperature of the working fluid and consequently the pressure. This is shown by the line 3–4, the volume of the gas being constant.

(iii) *Stroke three.*—The hot products of combustion at point 4 are at high pressure, consequently they force the piston down, and, expanding, fall in pressure. This expansion is assumed to occur without communication of heat to or from the gas, and is termed adiabatic expansion. This is represented by the line 4–5.

(iv) *Stroke four.*—At point 5 the piston is at the end of its stroke and no more expansion is possible. The exhaust valve now opens, and the pressure falls to atmospheric, as shown in line 5–2; throughout the last stroke 2–1 the exhaust valve remains open, and at point 1, the end of the cycle, the volume is again V.

Adiabatic compression and isothermal compression.

463.—(i) Adiabatic compression is one in which the heat resulting from compression is retained in the gas compressed.

(ii) Isothermal compression is one in which the heat resulting from compression is removed as rapidly as it is produced.

Work done by an engine.

464. The work done by any heat-engine is equal to the difference between the heat-energy that goes to the engine and that which is rejected by the engine, for whatever heat disappears cannot have been destroyed and must have been converted into work. In the ideal cycle no heat is rejected from the engine except during 5–2 (fig. 117), because when the charge gets back to the condition at 2 it has returned to its original volume and consequently its original temperature.

Thermal efficiency.

465. The thermal efficiency of the ideal cycle is the fraction of the heat supplied that is converted into work, that is $\frac{\text{(heat input)} - \text{(heat rejected)}}{\text{heat input}}$. In the theoretically ideal cycle, the thermal efficiency is calculated to be from forty to fifty per cent. All departures from the ideal decrease this efficiency to about half this value, so that the thermal efficiency of an average engine would be about 25 per cent.

Modification of the ideal cycle in practice.

466. In the previous paragraphs it was assumed that the pressure and expansion curves were adiabatic, that the walls of the cylinder extracted no heat, and that ignition and combustion were instantaneous and complete. None of these is true in practice. As an example, the cylinder cooling agent absorbs about forty per cent. of the total heat of combustion.

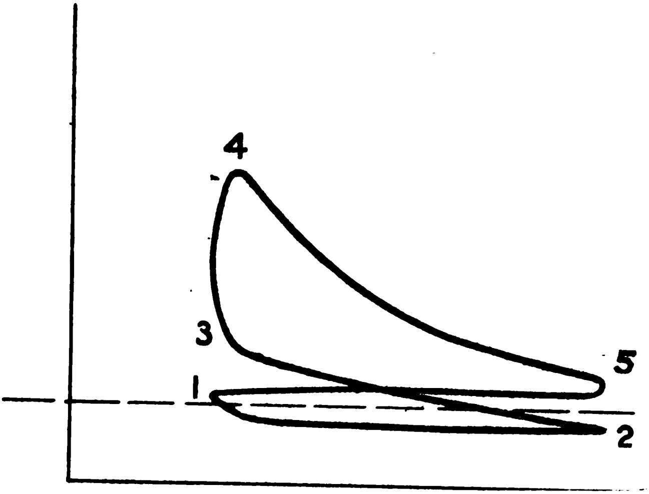


Fig. 118.—Normal.

Fig. 118 shows an indicator diagram of a normal engine.

Fig. 119 shows an indicator diagram of an engine with a slow rate of combustion, due to a weak mixture.

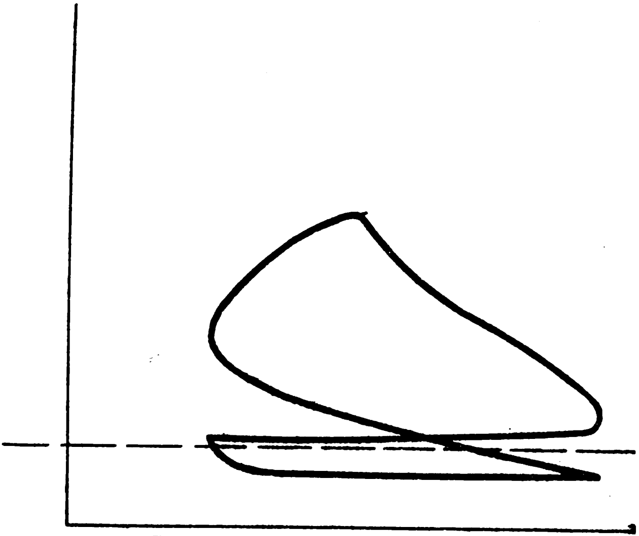


Fig. 119.—Slow rate of combustion.

Fig. 120 shows an indicator diagram of an engine with a very slow rate of combustion, which might be caused by a weak mixture and a very cold engine.

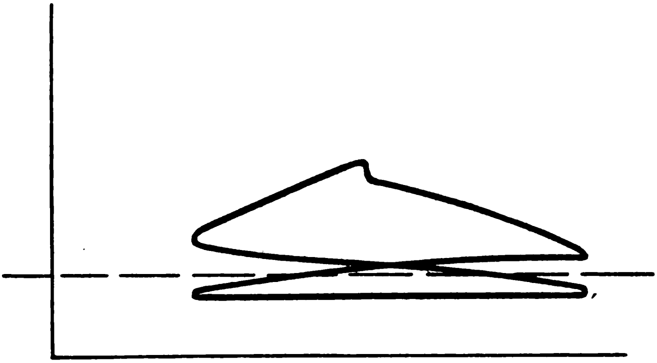


FIG. 120.—Very slow rate of combustion.

Fig. 121 shows the effect of pre-ignition.

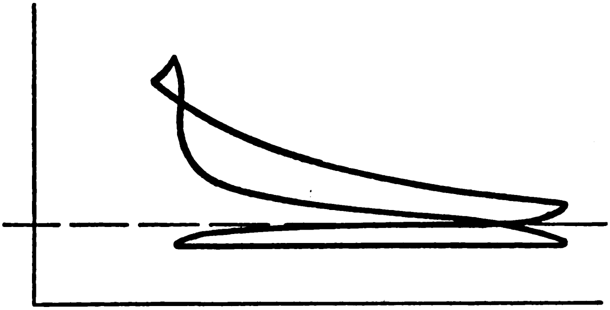


FIG. 121.—Pre-ignition.

Mechanical efficiency.

467.—(i) Useful work of an engine is that performed in producing the effect for which the engine is designed.

(ii) Lost work is that performed in producing other effects, as overcoming friction, etc.

(iii) The mechanical efficiency of an engine is a fraction expressing the ratio of the useful work to the whole work performed or energy expended. Mechanical efficiency $= \frac{\text{B.H.P.}}{\text{I.H.P.}}$ Internal combustion engines of good design have a mechanical efficiency of over ninety per cent.

Supercharger.

468. The supercharger has been developed to maintain the ground density of the charge when the aeroplane is flying at various altitudes. The density of the charge is increased about thirty per cent., which will allow the ground density

to be maintained up to about 10,000 ft., thus developing the normal B.H.P. at this altitude. As the density of the charge is increased the engine must not be opened out to full throttle at ground level, but must be gradually opened out as the altitude is increased. The method used at present is to put a fan in the induction system, which is driven from the crankshaft. This fan does not increase the rate of flow of the mixture to the combustion chamber, as the rate of flow is dependent upon the engine speed and the constructional details. The volume of the charge in the combustion chamber is not increased, as this depends on the compression ratio of the particular engine.

APPENDIX I.

STANDARD DRILL FOR THE SWINGING OF AIR SCREWS.

The standard drill for the swinging of airscrews is as follows. (The number and distribution of airmen normally required to start up a single-engined aeroplane are given below, but both number and distribution are subject to alteration according to the type of aeroplane) :—

(i) The detachment will be composed of one N.C.O. or airman-in-charge and three airmen.

(ii) As soon as the aeroplane has been moved into position ready for starting up, chocks, with the ends to which the cords are attached pointing inwards, will be placed under the wheels, the cord being carried outwards round the chock and back to the wing tip.

(iii) After the chocks have been placed in position, the N.C.O. or airman-in-charge will order the detachment to fall in two paces ahead of the airscrew facing the aeroplane, and will then detail the airmen to their duties as follows :—

No. 1.—Airscrew-swinger,—to stand by port wing tip.

No. 2.—Assistant airscrew-swinger (if required),—to stand by starboard wing tip.

No. 3.—To take post on the tail (if required).

If the aeroplane is fitted with a starting magneto operated from outside the fuselage an additional man will be necessary to work this magneto and assist No. 3 on the tail as soon as the engine starts.

(iv) The detachment will remain drawn up in front of the aeroplane until the N.C.O. has made his report to the pilot. This report deals with the condition of the aeroplane and engine, the amount of fuel in the tanks, whether the engine has been run up prior to the arrival of the pilot, and if so, the number of revolutions given.

(v) The pilot will then give any additional instructions with regard to ballast or other additional equipment required and will satisfy himself that the fuel is sufficient for the requirements of his flight.

(vi) As soon as the pilot takes his seat the N.C.O. or senior airman will give the command "Detachment take post," whereupon No. 1 will take up his stand in front but clear of the airscrew, No. 2 will double to the starboard wing tip or, if required at the airscrew, will take post with No. 1. No. 3 will double to the tail. On taking post the position of the detachment is as follows :—

(*a*) The N.C.O. or airman-in-charge will take up a position on the port side of the aeroplane whence he can superintend the airscrew-swinging, giving assistance if necessary, and can see the pilot and the switch, if the latter is outside the fuselage.

(*b*) No. 1 will stand at attention in front but clear of the airscrew.

(*c*) No. 2 (if not required at the airscrew) will stand at attention in front of the leading edge in line with the outer interplane struts facing inwards towards the engine.

(*d*) No. 3 will stand on the port side of the fuselage facing forward just in front of the leading edge of the tail-plane.

(vii) When ready to start the engine, the pilot will give the appropriate order as in column 1 of the subjoined table, upon which No. 1 will repeat it and commence to turn the airscrew. No. 2, if not assisting No. 1, will, while maintaining his position, bear against the outside forward inter-plane strut with his left hand and hold the cord of the chock with his right hand. No. 3 will turn to the right and lean forward over the fuselage, bearing his weight downwards on the longerons of the fuselage immediately over the inter-longerons struts. The procedure for swinging the airscrew will then proceed as laid down in the tables.

(viii) As soon as the engine starts No. 1 (and also No. 2 if he has been assisting No. 1) will double to their posts on the wing tips, turn outwards, and pick up the chock ropes as described above. The N.C.O. will take post forward and clear of the aeroplane where he can best see that the air and ground are clear and from where he can also see the pilot and No. 3.

(ix) When the pilot is ready to start off he acts as in paras. 145, 149 and 207, and the procedure continues as laid down therein.

(x) *When Hucks Starter is used.*

(*a*) N.C.O. or senior airman orders the detachment of three men to fall in, as before.

(*b*) As soon as the driver has manœuvred the starter into position the N.C.O. gives the order "Take post." No. 1 of the detachment jumps on the front platform of the Hucks starter and attaches the starting shaft to the fitting on the airscrew of the aeroplane. No. 2, if not required to assist No. 1, will double to the starboard wing tip. No. 3 takes post on the tail of the aeroplane as before.

(*c*) Pilot retards his spark and when No. 1 has given "All clear" the pilot gives "Switch off," "Petrol on," "Suck in."

(*d*) The Hucks starter is put into action.

(*e*) The switch should not be put at "Contact" until the engine has a good mixture and is revolving fast enough to prevent a back fire.

(*f*) As soon as the engine is running the Hucks starter is driven away.

(*g*) The detachment then take posts as in (viii) above.

DRILL FOR SWINGING AIRSCREWS.

I.—Mono Engine.

	1	2	3	4	5	6
Pilot - -	"*Switch off—petrol on.*"	—	—	"*Petrol off.*"	—	"*Contact*" and makes contact.
No. 1 of detachment.	—	"*Switch off—petrol on.*" Turns engine till one cylinder is at bottom with exhaust valve open.	"*Petrol off.*" Calls petrol off as soon as it is seen coming out of the exhaust valve.	Turns airscrew a few revolutions forward and adjusts for swinging position.	Standing clear—"*Contact.*"	—

	7	8	9	10	11	12
Pilot - -	—	If engine fails to start "*Switch off.*"	—	—	Continue as in 5, 6, 7.	
No. 1 of detachment.	Swings airscrew.	—	"*Switch off.*"	Adjusts airscrew for swinging.		

II.—ENGINE WITH NO SELF-STARTER.

	1	2	3	4	5	6
Pilot	“*Switch off—petrol on—suck in.*”	—	—	—	—	“*Contact*” and makes contact.
No. 1 of detachment.	—	“*Switch off—petrol on—suck in.*” Then swings airscrew to suck in.	—	—	Standing clear—“*Contact.*”	—

	7	8	9	10	11	12
Pilot	—	If engine fails to start “*Switch off.*”	—	—	Continue as in 5, 6, 7.	If engine still fails to start, this process is repeated. If it is necessary to swing the airscrew backwards owing to engine having too rich a mixture, pilot will give command “*Reverse,*” when No. 1
No. 1 of detachment.	Swings airscrew.	—	“*Switch off.*”	Adjusts airscrew for swinging.		

III.—Engine with self-starter, where swinging is NOT necessary.

	1	2	3	4	5	6
Pilot - -	"*Switch off—petrol on—suck in*"	—	—	—	—	"*All clear contact.*" Retards spark and makes contact.
No. 1 of detachment.	—	"*Switch off—petrol on—suck in.*" Swings airscrew to suck in.	—	—	Standing clear "*All clear contact.*"	—
No. 4 - -	—	—	—	—	—	—

	7	8	9	10	11	12
Pilot - -	—	If engine fails to start "*Switch off.*"	—	—		
No. 1 of detachment.	—	—	"*Switch off.*"	Adjusts airscrew to new position for starting.		
No. 4 - -	Manipulates self-starting magneto if self-starter is outside fuselage and not readily accessible to pilot.	—	—	—	Continue as in	5, 6, 7.

IV.—ENGINE WITH SELF-STARTER, WHERE SWINGING IS NECESSARY.

	1	2	3	4	5	6
Pilot	"*Switch off—petrol on—suck in*"	—	—	—	—	"*Swinging contact*" retards spark and makes contact.
No. 1 of detachment.	—	"*Switch off—petrol on—suck in.*" Swings airscrew to suck in.	—	—	Standing clear "*Swinging-contact.*"	—
No. 4	—	—	—	—	—	—

	7	8	9	10	11
Pilot	—	If engine fails to start "*Switch off.*"	—	—	Continue as in 5, 6, 7.
No. 1 of detachment.	Holding airscrew "*one-two-three-go,*" swings airscrew on word "GO."	—	"*Switch off.*"	Adjusts airscrew for swinging.	
No. 4	Manipulates self-starter on word "GO."	—	—	—	

N.B.—When starting big engines, No. 1 may have his free hand grasped by No. 2, so that he is pulled away from the airscrew after the swing.

HUCKS STARTER.

	1	2	3	4	5
Pilot	—	Retards spark "*Switch off—petrol on—suck in.*"	—	—	Makes contact when airscrew has done half a
No. 1 of de-					

APPENDIX II.

THE "AB INITIO" FLYING TRAINING OF PILOTS.

GENERAL REMARKS.

1. The initial training of pupil pilots is carried out as follows:—

(i) R.A.F. cadets at the Royal Air Force Cadet College, Cranwell.

(ii) Attached naval officers, seconded army officers, the larger proportion of short service commissioned officers and airmen at one of the flying training schools.

(iii) The remainder of the short service commissioned officers at certain service squadrons at home; these units are never squadrons or flights co-operating with the Army or Navy, nor are they those reserve and home defence squadrons that are maintained on a service basis.

2. The objects of the initial training of pupil pilots are:—

(i) To teach pupil pilots to manœuvre a service type of aeroplane accurately in the air and to handle the aeroplane correctly on the ground.

(ii) To teach pupil pilots to fly a service type of aeroplane from point to point by day in average weather conditions.

(iii) To ensure that such a standard of knowledge is reached in service subjects as will enable the C.O. of the Service unit to which the newly graduated pilot is posted to commence at once his individual training as a service pilot. C.Os. of service units should not have to waste time teaching a newly graduated pilot subjects which he should have learnt at the training unit.

3. The programme of work in ground subjects that have a direct bearing on practical flying will be so arranged that the instruction keeps pace stage by stage with the instruction in flying: that is to say, a pupil pilot will not be expected to learn the theory of flying across country by compass and D.R. navigation at a stage in his flying training when he is only just capable of flying round the aerodrome.

4. At units that are carrying out initial training of pilots (other than the Cadet College,—*see* para. 7), instruction in the theory of flight and meteorology will be given in the first term only; that in other ground subjects will be so arranged that during the first few months of the pupil pilot's training, only the elementary portion of each subject will be dealt with, in order that he may be the more capable of grasping the most important part of his instruction, *i.e.*, practical flying. Instruction in photography, oxygen apparatus, history and strategy and reconnaissance will be confined to the second term.

5. In para. 61 is a programme of work which gives a guide to the time that should be allotted to instruction in each of the subjects enumerated in paras. 13 to 60. It is not intended that this programme should be rigidly adhered to; but care must be taken to ensure that subjects such as meteorology, photography, oxygen apparatus are not given undue prominence at the expense, for instance, of such essential subjects as air pilotage or engines.

6. The ground instruction of all categories of pupil pilots will be the same (except attached naval officers, who are at present trained on a special syllabus in a course extending over seven months, and

R.A.F. cadets); but airman pilots will not be taught such items of discipline as are clearly only applicable to officer pupils. In place thereof airmen will receive instruction applicable to the duties of sergeants.

7. The training of R.A.F. cadets is dealt with in a syllabus adapted to a two-years' course at the Cadet College; that of all other classes of pilots to a course of eleven months at a flying training school or squadron carrying out initial training. At the latter units the sequence of flying and ground training will be as follows :—

8. *Sequence of flying training at flying training schools and in squadrons carrying out initial flying training :*

1st to 5th month - - -	Instruction in flying elementary training aeroplanes.
6th month - - - -	Break.
7th to 9th month - - -	Instruction in flying service aeroplanes.
10th and 11th months - -	Practice in flying service aeroplanes and passing out tests.
12th month - - - -	Leave and posting to unit.

As soon as a pupil becomes proficient on elementary training aeroplanes he goes on to service type aeroplanes.

9. Pupils will not leave the elementary training flights until they have passed out on the elementary training type of aeroplane.

10. When a pilot has passed out on a particular type of service aeroplane, he will be posted to a unit equipped with that type or with an analogous type of aeroplane.

11.—(i) *R.A.F. officers* will be taught to fly twin-engined bombing aeroplanes, single-engined bombing aeroplanes, army co-operation aeroplanes or single-seater fighter aeroplanes.

(ii) *Airman pilots* will be taught to fly one of the types of aeroplanes mentioned in sub-para. (i), other than army co-operation aeroplanes.

(iii) *Officers attached from the Royal Navy for initial flying training prior to joining a base training flight* will be taught to fly single-seater fighter aeroplanes or single-engined bombing aeroplanes.

(iv) *Officers seconded to the Royal Air Force from the Army* will usually be taught to fly a type of army co-operation aeroplane.

12. C.Os. of flying training schools will be informed at the commencement of each course of the number of pilots of each type required from the course. At the end of the first term they will allot R.A.F. officer, naval officer and airman pupil pilots for training on the various types of service aeroplanes in accordance with these requirements.

DETAILED SYLLABUS OF TRAINING AT FLYING TRAINING SCHOOLS AND IN SQUADRONS CARRYING OUT "AB INITIO" FLYING TRAINING.

PRACTICAL FLYING.

13. Pupil pilots will be required to pass all flying tests laid down in The King's Regulations and Air Council Iustructions, Volume II, Appendix III.

PRELIMINARY GROUND INSTRUCTION.

14. In order that pupil pilots may derive the greatest benefit from preliminary dual-control instruction both on elementary and service types of aeroplanes, it is essential that the various stages of flying instruction should be carefully explained to the pupil on the

ground before he commences dual instruction in the air. Pupil pilots must be instructed also in the aeroplane and engine controls; in the petrol, oil, and ignition systems; and in the starting and running of the engine of the particular type of aeroplane on which they are being taught to fly.

AIR PILOTAGE.

15. The object of instruction in air pilotage is to teach pupil pilots the correct methods of flying across country under varying conditions of weather. The instruction must follow a logical sequence, *i.e.*, it should keep pace with the pupil pilot's practical flying instruction.

16. The subject will be introduced by an explanation of the principles and uses of air pilotage. The methods employed in map and chart making will then be explained, while the reading of conventional signs on maps and the proper ways of measuring courses and distances on charts will be taught.

17. Instruction will then be given in elementary magnetism and the principles of construction and use of the magnetic compass. The principles of D.R. navigation, the triangle of velocities and the solution of D.R. navigation problems by graphical methods will then be explained.

18. More detailed instruction in the construction, care and adjustment of compasses and in the construction and use of all the other instruments used in air pilotage, such as drift indicators and course calculators, will then be given. A large amount of time must be devoted to practical compass adjustment.

19. Practical ground instruction in the carrying out of cross-country flights by means of air pilotage and D.R. navigation will now be given and should lead up to the actual use of the various methods of air pilotage and D.R. navigation in the air.

20. A large proportion of the time available must be devoted to practical work on the ground in order to habituate pupil pilots, when flying across country, to steering by compass, to keeping a constant check on their position and to reasoning methodically when apparently lost.

AIRMANSHIP.

21. The object of instruction in airmanship is to teach pupil pilots to handle their aeroplanes and engines correctly on the ground and in the air. Airmanship can therefore be divided into two portions: " Airmanship on the ground " and " Airmanship in the air."

22. *Airmanship on the ground.*—This will include the care and maintenance of aeroplanes in the hangar; inspection of aeroplanes and engines; moving aeroplanes and engines in and out of hangars; preparations before starting up and the starting up of engines; special points for the running of stationary, rotary and static radial engines; airscrew swinging and drill; engine troubles with their symptoms and causes; care and maintenance of aeroplanes in the open, and action to be taken by a pilot after a forced landing. The provisions of Chapter XII, Sections I–V of The King's Regulations and Air Council Instructions relating to flying must also be known by pupils.

23. *Airmanship in the air.*—This will include the principles of control in the air and the effect of the controls in the air; the method of executing the evolutions of normal flight and of aerobatics; the execution of forced landings, including the selection of suitable ground for them.

THEORY OF FLIGHT.

24. The object to be aimed at in the theory of flight is to give pupil pilots sufficient instruction to enable them to understand why an aeroplane flies; what are the functions of its controls; and the effect that its weight and horse-power have on the flying qualities of the aeroplane. The ground covered by Chapter II of this Manual is all that is necessary for this purpose. Instruction in the subject should be completed during the first term.

METEOROLOGY.

25. Instruction in meteorology will, as far as possible, be given concurrently with that in air pilotage. It must deal very broadly with the types of pressure systems such as cyclones and anti-cyclones, and the weather to be expected with each type; how to read and understand a weather map; and the probable effects upon weather conditions of changes in atmospheric pressure at sea level. An explanation must be given also of the principles of construction of the barometer.

ENGINES AND MAGNETOS.

26. Instruction in engines and magnetos must commence with an explanation of the theory of internal combustion engines both of the four-stroke and two-stroke cycle, and will then deal with the following points :—(i) The functions of the various parts of an internal combustion engine; (ii) relation between piston displacement and horse-power developed; (iii) the various metals of which an engine is constructed; (iv) advantages and disadvantages of water and air cooling; (v) general description of the types of engines in use at the flying training school or unit concerned; (vi) advantages and disadvantages of rotary, static-radial and stationary engines; (vii) instruments.

27. The various parts of an internal combustion engine must now be fully examined. Ignition and carburation systems should be dealt with, including an explanation of the magneto, its component parts and how it works, together with a little elementary instruction in electricity and magnetism, sufficient to enable the pupils to appreciate the principles that govern its working.*

28. Further instruction will include :—Dismounting and installing aeroplane engines; timing, stripping and assembling; running repairs, special attention being given to small running faults such as might cause loss of revolutions, missing, choking, &c.—any possible cause, in fact, of a forced landing due to engine failure and an explanation of the remedy.

29. The type of engine, in use at the flying training school or unit, on which the pupil pilots will finally pass out, must be fully dealt with, and must include detailed instruction and practice in starting up and running the engine.

30. As much of this work as possible must be practical, and the aim should be to turn out a pilot capable of taking an active and intelligent interest in the engine of his aeroplane and one who can himself execute simple running repairs.

31. Instruction must be given also in petrol and oil systems and possible causes of failure; high-altitude control; the proper care and running of an engine in the air; precautions when starting; explana-

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* NOTE.—Since elementary electricity and magnetism are dealt with under air pilotage, engines and wireless co-ordination will be necessary to avoid needless repetition and overlapping.

tion of how the parts of an engine are overloaded by exceeding normal r.p.m. and how fatigue can be lessened by easing the r.p.m. whenever possible; forced induction and supercharging.

32. Instruction will also be given in engine repair shop procedure.

RIGGING.

33. Elementary instruction must be given to commence with in the general principles of rigging. This will include an explanation of the various parts of an aeroplane, the loads to which they are subjected, and the effect of various parts being out of truth, explanations being given as to why an aeroplane is tail heavy, nose heavy, flying one wing down, or unstable either laterally or fore and aft. This instruction must be kept as practical as possible and special attention will be given at first to the elementary training aeroplane.

34. The practical correction of the rigging faults dealt with during earlier instruction must now be considered and special attention paid to the rigging of the type of aeroplane on which the pupil pilot will finally pass out.

35. Pupil pilots must receive sufficient instruction to enable them to supervise intelligently the erection of an elementary training aeroplane and two types of service aeroplanes, and to carry out themselves minor alterations and repairs. One of the two types of service aeroplane should be that on which the pupils will pass out.

36. They should understand how to true up their aeroplane; test the angle of incidence of the main and tail planes; test the angle between the main planes and tail plane; they should know the places where controls are most likely to fray, and be able to renew controls.

37. They should further understand what particular part of an aeroplane should be examined for damage or strain after a heavy landing.

38. The functions and operation of the tail-adjusting gear must be thoroughly understood.

39. Instruction should be given in aeroplane repair shop procedure.

PHYSICAL TRAINING.

40. Physical fitness is of the utmost importance to all flying personnel and more especially to aeroplane pilots. Pupil pilots must therefore carry out physical training for at least 2½ hours a week throughout the course. The value of organised games (*e.g.*, cross-country runs) should not be overlooked.

DRILL.

41. Pupil pilots must be thoroughly trained in drill and march discipline in order to fit them to take command of bodies of airmen and to instil in them a sense of corporate discipline.

42. Instruction in drill must be carried out progressively, commencing with squad drill without and with arms.

43. Pupil pilots must be thoroughly proficient in squad drill before they are allowed to proceed to flight and squadron drill.

ADMINISTRATION.

44. At the beginning of a pupil pilot's training, instruction must be confined to showing in broad outline the principles upon which the administration of the R.A.F. unit to which he belongs is based. Having grasped these basic principles, the pupil must be given more detailed

explanation of administrative methods. Thus at a flying training school the pupil pilot must be made to understand first the reasons for the devolution of the responsibilities of the C.O., and secondly the manner in which such responsibilities are allotted amongst squadron leaders in charge of flying, administration and technical duties, the station adjutant and the subordinates of these officers.

45. Later, preferably in the second term, more detailed instruction in the duties of these officers should be given, as under:—

(i) *Welfare of airmen.*—Service institute, derivation and expenditure of non-public funds, control of institutes; airmen's messing, augmentation of daily rations by purchases from Navy, Army and Air Force Institutes; organisation of sports and games and upkeep of sports grounds and sports equipment.

(ii) *Stores accounting and store-keeping.*—This subject must be dealt with mainly from the point of view of an officer in a flight, such as the care and accounting for stores on charge of the flight commander, the manner of dealing with deficiencies, methods of obtaining stores and issuing articles to individual airmen, flight inventories. In addition, a general idea of the stores accounting system of a unit must be given.

(iii) *Financial accounting.*—A general idea of the system of accounting for public and non-public funds must be given. A more detailed explanation must be given on such points as airmen's pay; officers' sergeants' and airmen's mess finance; services institute and sports funds and the responsibilities of officers in charge of non-public funds. Elementary instruction in bookkeeping should also be given.

(iv) *General points of administration.*—Office routine and organisation, airmen's documents and methods of keeping them up to date, leave passes, returns and the reasons for rendering them.

(v) Duties of adjutant, orderly officer, sergeant major, orderly sergeant and corporal as regards administration. Guard duties, guard reports, police and sentry duties.

(vi) M.T. regulations, fire fighting and fire orders. Kit inspection, inspection of airmen on parade.

(vii) *Promotion, remustering and reclassification of airmen.*—A general idea must be given of the various "trades" in the Royal Air Force and the methods of advancement or reduction of airmen either in regard to rank or trade group.

(viii) *Hygiene.*—Instruction must aim at impressing on pupil pilots the necessity for and the principles of hygiene with special reference to its bearing on food and water. Instruction must be given also in the duties of the sanitary squad and correct methods of carrying out barrack inspection; the general precautions against diseases, with special regard to disease carriers such as house flies, mosquitoes, and sand flies should be referred to.

LAW AND ITS APPLICATION TO THE MAINTENANCE OF DISCIPLINE.

46. *Law.*—(i) The object of instruction in law will be to show pupil pilots the necessity for and the principles of air force law and its relation to civil law; and to teach them how to use and apply the Manual of Air Force Law and The King's Regulations and Air Council Instructions for the Royal Air Force in dealing with minor offences by airmen.

(ii) The following are among the points that must be dealt with:—Powers of C.Os. and other officers, minor offences by airmen, arrest and custody of airmen, escorts, award of appropriate punishments, fines, forfeiture and stoppage of pay, desertion and absence without leave, civil offences, framing of charges and summaries of evidence, conduct sheets, assessments of character and billeting of airmen.

47. *Discipline.*—(i) Pupil pilots must be taught how to maintain discipline without resort to the application of the penalties provided for by air force law, and must know the duties of warrant officers and N.C.Os. in regard to discipline, and the duties of the N.C.Os. in charge of guard and of sentries or service police; how to deal with applications and/or complaints by airmen; how to deal with breaches of discipline by airmen in various circumstances whether in or out of barracks; orderly room procedure.

(ii) Lectures must also be given on etiquette and customs of the service in and out of barracks; inter-rank relations and relations with officers and men of other services; how to address airmen and to give an order; returning of salutes; paying compliments to senior officers ashore and afloat; service and unit *esprit de corps*.

(iii) Airman pupil pilots will be instructed in the above in so far as it is applicable to the rank of sergeant; during lectures that are not applicable, they will be employed at their trades in flights.

ORGANISATION OF THE ROYAL AIR FORCE AND OTHER SERVICES.

48. A general idea of the higher organisation of the Royal Air Force must be given. This should include—

(i) A general knowledge of—

(*a*) the composition of the Air Council and the duties of its members;

(*b*) the organisation of the Royal Air Force into commands and of the functions of each command;

(*c*) the duties of the air personnel, technical and stores staff of commands.

(ii) a detailed idea of the types and duties of the various service squadrons, fleet air arm and naval co-operation flights and the R.A.F. training establishments, depôts and parks;

(iii) a general idea of the administration and characteristics of the various arms of the Army and the organisation of an artillery, cavalry and infantry brigade and of an infantry division; and

(iv) a general idea of the fighting characteristics of the various types of war vessels of the Navy and the composition of a fleet, special attention being paid to aircraft carriers.

ARMAMENT.

49. As soon as the pupil pilots have received sufficient training in elementary musketry and have passed their standard tests before firing, practice must be commenced on the 25 yards machine-gun range with the rifle and ·303 ammunition. This must be regarded as an introduction to the use of the machine gun, which must not be attempted until the pupil pilot has mastered the rifle.

50. After this preliminary training, instruction must be commenced on the syllabus of the initial course of ground gunnery laid down in Air Publication 883. Instruction in the initial course of ground gunnery must be completed. Sufficient instruction will be given to ensure that a pupil pilot understands how to handle explosives safely and how to place a bomb in its rack, and adjust the release gear.

W/T AND/OR R/T AND MORSE CODE.

51. The basis of the efficient use of wireless communication is first a capacity to send and receive messages in morse code correctly and rapidly, and secondly a thorough practical knowledge of the functioning and use of the various instruments comprising a wireless set. Pupil pilots must therefore be given constant practice throughout the course in sending and receiving in morse code.

52. Pupil pilots must also be given sufficient instruction in the theory of wireless transmission to enable them to understand the functioning of the instruments that they will use in the air.

53. Practical instruction in the operation of wireless instruments must then be commenced, and should include practical instruction in the use and tuning of the instruments in the air, and the examination and testing of the apparatus before the commencement of a flight. This practical instruction will, in flying training schools and single-engined and twin-engined bombing squadrons that are carrying out initial training, deal with W/T instruments. In single-seater fighter squadrons carrying out *ab initio* training, instruction in R/T instruments will be given.

PHOTOGRAPHY.

54. Instruction in photography must be strictly practical, and will be limited to an explanation of the types of cameras used for air work; method of fitting into an aeroplane; handling and loading of plates; types of photographs required and how they are taken; heights at which to take the various types of photographs.

55. Pupil pilots will also be given practice in actual air photography and on completion of the course should have a thorough knowledge of the practical use of the camera on the ground and in the air.

56. Pupil pilots in single-seater fighter units will not receive instruction in photography.

HISTORY AND STRATEGY.

57. Lectures on the history of the Royal Air Force must be confined to broad outlines and must deal only with the origin and development of the Royal Naval Air Service and Royal Flying Corps, and the evolution of the Royal Air Force from these two branches of the older services. The instruction should aim, not at giving a complete historical record of the Royal Air Force, but at supplying pupil pilots with a guide upon which to conduct their reading of the historical text books.

58. The objects of lectures on strategy are to create an intelligent interest in the subject in the minds of pupil pilots and to indicate the lines upon which they should conduct their private reading. Instruction in strategy must therefore be confined to broad outlines only.

RECONNAISSANCE AND REPORT WRITING.

59. When pupil pilots have attained such a stage in their flying instruction that they are capable of carrying out cross-country flights on their service type of aeroplane, they must be given instruction in the methods of making a reconnaissance and writing a report on it. They must also carry out practical reconnaissances during their cross-country flights and make written reports on the completion of the flight.

OXYGEN APPARATUS.

60. Instruction in the use of oxygen apparatus must be confined to ground instruction. The disadvantages of and physical disability caused by flying at high altitudes without oxygen must be emphasised. Pupil pilots must be shown clearly that any discomfort and inconvenience caused when using oxygen apparatus is more than compensated for by the benefits derived from its use.

PROGRAMME OF WORK.

61. The following table shows the programme of work for a course of training :—

Subject.	Hours, 1st term, 22 weeks	Hours a week.	Hours, 2nd term, 22 weeks.	Hours a week.	Total hours each course.
1. *Flying, &c.*					
Practical flying Ground instruction in flying training	253	11½	253	11½	506
Air pilotage	44	2	44	2	88
Airmanship	33	1½	33	1½	66
Theory of flight	5½	½ hour alternate weeks.	—	—	5½
Meteorology	11	½	—	—	11
2. *Aeronautical engineering.*					
Engines and ignition	55	2½	55	2½	110
Rigging	44	2	44	2	88
3. *Physical training and drill.*					
Physical training	55	2½	55	2½	110
Drill	33	1½	33	1½	66
Parades	11	½	11	½	22 (Does not include Colour hoisting parade.)
Organised games (compulsory)	44	2	44	2	88
4. *Interior economy.*					
Administration	44	2	44	2	88
Discipline Air force law	22	1	22	1	44
Organisation	5½	½ hour alternate weeks	5½	½ hour alternate weeks	11
5. *General services subjects.*					
Armament	77	3½	77	3½	154
W/T and/or R/T and morse	44	2	44	2	88
History and strategy	—	—	5½	½ hour alternate weeks	5½
Reconnaissance and report writing	—	—	5½		5½
Oxygen apparatus	—	—	5½		5½
Totals	781	35½	781	35½	1,562

EXAMINATIONS AND ALLOTMENT OF MARKS.

62. Examinations will be held at the end of the first and second terms as shown in the table of allotment of marks below. In theory of flight and meteorology, instruction in which is confined to the first term, examinations will be held at the end of the first term only. Similarly, in photography, oxygen apparatus, history and strategy, and reconnaissance, instruction in which is confined to the second term, examinations will be held at the end of the second term only.

63. A proportion of the papers at each examination will be set and marked by external examiners.

64. Pupil pilots must obtain fifty per cent. of the aggregate marks in the examination at the end of the first term; in the final examination at the end of the second term they must obtain sixty per cent. of the aggregate marks and fifty per cent. of the marks allotted to each subject.

65. The following are the subjects in which pupil pilots will be examined and the allotment of marks to each subject :—

WRITTEN EXAMINATION.

Subject.	*1st term.*	*2nd term.*
Air pilotage and meteorology	200	350
Airmanship	200	200
Internal combustion engines (theory)	200	300
Administration and organisation	200	250
Law and discipline	100	250
History and strategy	—	100
Theory of flight	100	—
Neatness and arrangement of notebooks	—	50
	1,000	1,500

PRACTICAL EXAMINATIONS.

Subject.	*1st term.*	*2nd term.*
Engines	200	300
Rigging	200	300
Signals { Morse code W/T sets or R/T sets. }	150	150
Armament	200	300
Photography and writing reconnaissance reports	—	100
Oxygen apparatus	—	50
Drill	50	100
	800	1,300

APPENDIX III.

INSPECTION AND MAINTENANCE OF AEROPLANES.

1. The C.O. of a flying unit will be responsible for issuing adequate and detailed orders for the inspection and maintenance of aeroplanes of his unit in accordance with the existing regulations. Such orders will be issued and signed by the C.O. of the unit personally; he is not

permitted to delegate that responsibility to subordinates. Such orders will be issued primarily for the purpose of—

(i) ensuring the safety of personnel.

(ii) the maintenance of aeroplanes in a serviceable condition.

(iii) defining responsibility for inspection of, and work on, aeroplanes.

(iv) sufficiently recording to what extent each aeroplane has been inspected and what work has been done upon it.

2. Each aeroplane in use will normally be put under the charge of an officer or airman pilot who will be responsible to the flight commander that all required inspections are carried out. Save in exceptional circumstances not more than two aircraft are to be placed in the charge of one officer or airman pilot. Flight commanders are to make percentage checks at least once weekly in order to ensure that the routine inspection as laid down for the unit is being properly carried out. Such percentage checks are to be made daily by officers and airman pilots in charge of aeroplanes. Complete inspections of aeroplanes will be made frequently by the flight commanders and by officers and airmen in charge of aeroplanes at such times and periods as may be laid down in the orders for the unit.

3. A record to be known as the "Aeroplane Inspection Book" is to be kept in each flight for all aeroplanes in that flight, in which the following information will be entered daily in ink or indelible pencil:—

(*a*) The result of all inspections, initialled by the fitter and rigger and by any other person by whom an inspection was checked or independently carried out.

(*b*) The time at which any aeroplane has been found unserviceable and declared as such in accordance with para. 5.

(*c*) The time at which any aeroplane declared unserviceable in accordance with (*b*) above was declared to be serviceable, and the initials of the person who ordered the "Unserviceability board" to be removed in accordance w*t*th para. 4.

(*d*) Whether the officer or airman pilot in charge of the aeroplane is satisfied that the aeroplane is fit to be flown or otherwise. This will be initialled by the officer or airman pilot concerned, and if he considers that the aeroplane should not be flown his reasons will be briefly stated.

(*e*) A short statement of any modification, repairs or alteration ordered, put in hand, or completed.

(*f*) Any other information which in the opinion of the C.O. of the unit or the flight commander, should be recorded.

(*g*) A notification initialled by the flight commander that he has seen and concurs or otherwise with (*a*), (*b*), (*c*), (*d*), (*e*) and (where necessary), (*f*) above.

The aeroplane inspection book for each flight will be inspected and initialled monthly by the C.O. of the unit. Detailed records of modifications, repairs and alterations will be entered in log books as heretofore.

4. A board to be known as the "Unserviceability board" marked in red letters "UNSERVICEABLE" will be kept for each aeroplane, and if the aeroplane becomes unserviceable it is the duty of the fitter (if the unserviceability depends on the engine or any component for which the fitter is responsible), or the rigger (if the unserviceability depends on any other part of the aeroplane, including the special equipment and installations referred to in para. 9 with regard to which he must obtain reports from the responsible airmen concerned), at once to hang the "Unserviceability board" in a conspicuous

place on the forepart of the aeroplane and immediately to make the necessary entry in the aeroplane inspection book. The "Unserviceability board" will be removed only on the orders of the flight commander or officer, or airman pilot, in charge of the aeroplane and not until the necessary entry has been made in the aeroplane inspection book.

5. Whenever the officer or airman pilot in charge of, or any other pilot flying, an aeroplane considers that for any reason it is unserviceable, he will at once instruct the fitter or rigger accordingly and personally see that the aeroplane is declared to be unserviceable. At Flying Training Schools where pupil pilots are in charge of aeroplanes, the pupil will report unserviceability to the flight commander and not to the fitter or rigger.

6. Whenever practicable, at least one fitter and one rigger will be allotted to each aeroplane.

7. The fitter or fitters will be made responsible for the engine, engine ignition, starting devices, fuel oil and cooling systems, and all wiring, piping, accessories, instruments and controls in connection therewith. The fitter or fitters will also be made definitely responsible that the ignition switches are off, chocks in position, all tanks full and that all cocks are in their proper operative positions before the pilot takes his seat in the aeroplane preparatory to flight. With regard to the airscrew, the fitter's responsibility will be limited to the attachment of the airscrew to the airscrew shaft in the case of wooden airscrews, but in the case of metal airscrews, he will also be responsible for the airscrew itself, and for any gearing and controls operating it.

8. The rigger or riggers will be made responsible for the aeroplane and its components, equipment and accessories, except such equipment and installations for the maintenance of which specially trained airmen are allowed on the strength of the unit concerned, *e.g.*, armament, wireless and photographic equipment. With regard to these, however, the rigger or riggers, and fitter or fitters, as appropriate, will be held responsible that such equipment is installed in such a manner as not to prejudice the safety of the aeroplane or the efficiency of the engine.

9. With regard to aeroplanes fitted for night flying, unit orders will ensure that the electrician or electricians are made responsible for the installation and efficient working of all electrical equipment peculiar to night flying.

10. Every aeroplane is to be inspected at least twice during each day, *i.e.*, before flying starts and after flying terminates. It will also be inspected at such other times, *e.g.*, after every 25 hours' flying, as circumstances may dictate, or in accordance with any special instructions that may have been issued with regard to a particular aeroplane or engine.

11. Unless special sanction to the contrary has been previously obtained from the Air Ministry, aeroplanes, after a maximum of 400 hours' flying at home, if housed on shore at a home unit, or 200 hours' flying, if housed in an aircraft carrier or in a unit overseas, except as stated below, are to be allotted to the appropriate aircraft depôt for complete overhaul. The officer commanding the aircraft depôt will, on completion of such overhaul, cause all necessary entries to be made in the log book and will furnish a certificate to the area or command concerned that all necessary repairs and renewals have been effected. In Iraq, India or Middle East, the continued use of an aircraft after 200 hours' flying-time may be authorised by

the air officer commanding up to a maximum of 300 hours, on the recommendation of a board of officers, provided that the board shall consist of three officers of whom one shall be an experienced technical officer and that the members of the board have inspected the aircraft.

With regard to engines, action will be taken, on application from the C.O. of the unit to the area or command concerned, at such times and periods as may be found necessary.

12. An aeroplane, after completing the number of flying hours prescribed from time to time for its type, either since construction or since last complete overhaul, will be inspected by a competent officer obtained or detailed by the C.O. of the unit. A report of the inspection will be entered in the log book of the aeroplane by the inspector and signed by the C.O. of the unit, who will be responsible that action is taken to remedy any defects disclosed.

13. An aeroplane, after completing the prescribed number of flying hours, will be despatched to an aircraft repair section or repair depôt, or notified to the Air Ministry for reconditioning by a contractor. During reconditioning the aeroplane will be dismantled, inspected in close detail, repaired as necessary, and brought up-to-date in accordance with the reconditioning specification for the type. A report of the inspection and particulars of all work carried out will be made in the log book of the aeroplane, and the C.O. of the aircraft repair section or repair depôt will certify therein, before the aeroplane is re-issued, that all necessary renewals and repairs have been effected.

14. On completion of any alterations, adjustments or modifications, affecting the air worthiness of an aeroplane, the aeroplane will not be flown until the work has been inspected by the flight commander, or by an officer deputed by him. After the work has been inspected and passed, the aeroplane will be tested in the air, and will not be used for the purpose of instruction or carrying a passenger, other than the airman concerned with the alterations, adjustments or modifications, until this test has been carried out and the work proved to be satisfactory. If the alterations, adjustments or modifications, be such as to bring the aircraft in conformity with standard type, the C.O. may at his discretion, dispense with the test in the air, where such tests delay or interfere with the operation of the unit.

15. Nothing contained in this Appendix may be regarded as modifying existing instructions with regard to the proper keeping of log books.

ENGINES.

16. Detailed information regarding the maintenance of all types of engines in service is contained in the instructional handbooks which can be obtained on application to the Air Ministry, through the usual channels.

17. C.Os. of units will be responsible that the instructions in those handbooks are complied with, and that sufficient copies of the appropriate handbooks are available for the use of all officers and airmen concerned with the inspection and maintenance of engines.

AEROPLANES (EXCLUDING ENGINES).

18. The interval between inspections of the various parts of aeroplanes will vary with the conditions under which the aeroplanes are used, the climatic conditions, etc.

19.—(i) For convenience, the aeroplane parts can be divided into the following categories :—

A.—Parts subject to wear and tear, *e.g.*, control mechanisms, control wires, pulleys, rocking shafts, control hinges and wheels.

B.—Parts subject to abrasion and shock loads, *e.g.*, chassis, wheels and tyres, tail-skids, floats and boats.

C.—Parts subject to concentrated stress, deterioration, corrosion or distortion, *e.g.*, structure metal parts, timber parts, fabric and rubber.

D.—Parts requiring cleaning, *e.g.*, tanks, filters, radiators, etc.

(ii) As regards category A, all these parts should be inspected at regular intervals.

Control wires should be inspected at least once a week for fraying of cables. Rocking shafts, pulleys, hinges and wheels should normally be inspected daily and should be lubricated weekly. The fittings for keeping the wheel in place should be inspected at the daily inspection.

(iii) As regards category B, these parts should be inspected at frequent intervals.

Tyres and other rubber parts, especially in the East, should be inspected frequently for signs of deterioration. Defects are seldom difficult to detect, and the maximum intervals between inspections will depend on the position and functions of the part concerned. Chassis and tail-skids should be inspected daily. Defects in these are usually obvious.

The structure supporting the chassis and tail-skid should be thoroughly inspected once a week. It should be specially inspected after a heavy landing.

(iv) As regards category C, these parts should be inspected periodically.

Timber parts in ordinary use are usually quite reliable, but unless inaccessible should be inspected once a month. If, however, built-up spars or struts are used, these and the glued joints should be examined as opportunity offers.

Timber parts in hot climates require more frequent inspection to detect shrinkage which may cause fittings to become loose.

Airscrews require external examination only. The joints of the laminations are the weak points.

Fabric is quite reliable, but should be made part of the daily inspection.

Dope must be maintained in good condition.

Metal airscrews should have the welded seams and sockets examined daily.

The weakest parts of most aeroplanes are the attachments and joints. These and other metal parts should be inspected at intervals depending on their relative importance, *e.g.*, the fastenings of the main plane spars to the fuselage should be inspected daily, and at the same time undue corrosion, particularly in seaplanes and ship-planes, should be looked for.

A general inspection of the rigging should be carried out daily. This will give a fair indication if any movement is taking place in the attachments. If an aeroplane requires constant re-rigging, it shows that the structure is deforming, and the aeroplane should be stripped for internal inspection.

(v) As regards category D, these parts should be cleaned regularly.

Once a month the inside and outside of the tanks should be examined for signs of corrosion. The flow of water through the radiators should be tested to detect signs of furring. The interval between such inspections will depend on the water supply, *e.g.*, whether hard or soft water is available. Filters should be cleaned out daily unless they are in such a position as to make this impracticable.

APPENDIX IV.

CARE AND MAINTENANCE OF THE SURFACE IN THE VICINITY OF SHED APRONS.

1. Except when fighter squadrons are practising "readiness" or "patrol drill," aeroplanes must not be turned in the vicinity of the shed apron. All turns must be made either on the apron or well away, *i.e.*, at a distance of over fifty yards from it. Turns should be gradual, as sharp turns, particularly when the inner wing is held by airmen, tend to cut up the ground badly. As a general rule aeroplane traffic should leave and return from and to the apron by the sides in wet weather, if the lay-out of the sheds and aprons enables this to be done, but in any case the object should be to disperse traffic and thus to prevent wear and tear at any particular places.

2. Heavy lorries should not as a rule be allowed on the aerodrome, nor is it desirable that light tenders should run across the aerodrome except when the surface is dry and hard in the summer. This applies particularly to aerodromes that have been mole-drained, since one trip across the lines of the mole-plough will block all the drains, unless the surface of the aerodrome is exceptionally hard.

3. As a general rule engines must be started up on the apron whether started by hand or by Hucks starters. If it is necessary to start an engine out on the aerodrome and if a Hucks starter is used it should leave from the side and return to the side of the apron.

4. Care must be taken when doping rotary engines to prevent, as far as possible, petrol from dropping on the grass, as petrol kills it.

5. Pedestrian traffic in front of the apron must be limited to the minimum requirements.

6. Ambulance and light tender traffic on the aerodrome must, as far as possible, avoid the surface in front of the aprons.

7. Precautions to conserve the surface of aerodromes in front of aprons are just as important in dry weather as in wet, as if the grass is killed or weakened in dry weather, in wet weather the area in front of aprons quickly degenerates into a slough.

APPENDIX V.

PREVENTIVE HYGIENE IN RELATION TO FLYING.

1. What may, broadly speaking, be called preventive hygiene plays an important part in maintaining flying efficiency.

2. *Care of the Eyes.*—Owing to the importance in flying of good visual judgment, care should be taken to prevent the development of any condition of the eyes or eyelids which, if allowed to progress, may result in definite deterioration in the power of making accurate visual judgments, especially in respect of landings. Pilots vary greatly in their power to resist the effects upon the eyes of dust, wind and glare. On this account, therefore, the best advice in respect of the use of goggles when flying is always to wear them. In the tropics the use *on the ground* by all flying personnel of anti-glare glasses with protective side screens is advisable, more especially during the hot

seasons. It is to be remembered that it is of little service to wear protective goggles in the air under these conditions, and to neglect the true precautions on the ground where the degree and length of exposure to the irritant causes of eye trouble are more extensive and more prolonged. Moreover, it is of little use to start wearing such protective glasses after the damage has been done; their proper use being to prevent, not to alleviate or cure.

3. *The Care of the Ears, Nose, Throat and Teeth.*—In flying, particularly in high flying, it is very important that the pilot be able to accommodate himself to the effects of diminished pressure upon the air enclosed within the ear cavity. The orifice of the external ear affords a wide passage by which alterations of air pressure are easily transmitted to the outer side of the ear drum; but the Eustachian tubes (the narrow passages which lead from the back of the throat to the inner side of the ear drum) normally open only during the act of swallowing, and, therefore, do not so readily transmit pressure changes. Any catarrhal condition or congestion of these tubes, therefore, will tend to produce difficulty in the equalisation of pressure within and without the tympanic cavity. The differences of pressure which may arise on either side of the ear drum are not always fully appreciated. Generally speaking, during an ascent the ears are unconsciously "cleared" by swallowing, which under ordinary circumstances is sufficient to open the Eustachian tubes and equalise the pressure on both sides of the drum. Occasionally a very graduated self-inflation, as described later, just sufficient to open the tubes may be required to dispel the sensation of fullness. If. however, owing to very marked obstruction of the Eustachian tubes no equalisation of pressure has taken place, then at 20,000 feet the pressure on the outer side of the ear drum is approximately 380 mm. Hg. while in the middle ear, on the inner side of the ear drum, it is still 760 mm. Hg., a difference of 380 mm. Hg.; this tends to push the drum outwards. If, on the other hand, during the relatively slow ascent, equalisation of pressure is made, but owing to Eustachian obstruction little or no equalisation is made during a rapid descent, then, on reaching ground level, there is a pressure of 760 mm. Hg. on the outer side of the ear drum, but only about 380 mm. Hg. on the inner side of the ear drum; this tends to force the drum painfully inwards. It is on this account that sometimes, after landing, pilots complain of deafness, discomfort or pain in the ears, as well as in certain cases of unpleasant symptoms prior to landing. It is important to remember also that one-sided Eustachian obstruction has been found to give rise to trouble in the air.

For equalisation of the air pressure within the ears it is important to be able to swallow satisfactorily; and for this reason there is much to recommend the use of chewing gum in the air, since this provides the saliva necessary for the act of swallowing. The upper air is relatively dry, and, after flying at high altitudes, the throat is apt to get parched, and during descents difficulty in swallowing is experienced. This can be overcome by the use of chewing gum. In some cases, however, during descents, swallowing is not sufficient to equalise the pressure within the ears, particularly in sharp descents. This being so, if a descent be very sudden, the pressure within the tubes is in many people best increased and equalised by gently inflating the ears; namely, by pinching the nostrils, closing the lips tightly, and then gently, by the use of the abdominal muscles, forcing the air out of the chest into the nose and ears until a clicking sound is heard in both ears. Such self-inflation should be gentle, and should be practised about once in every 1,000 feet of the descent.

Sometimes, as for example when wearing an oxygen mask, self-inflation is not possible owing to inability to grip the nose. A simple procedure for equalisation of pressure within the ears, which may be practised instead of self-inflation, is as follows :—

Open the mouth slightly, as if beginning to yawn, maintaining the lower teeth as far in front of the upper as possible, The effort can only be sustained strongly for a minute or less, and one should be conscious of tightly contracting the muscles of the palate and upper throat at the same time If the procedure succeeds, this opens the normally closed Eustachian tubes and one can pass through considerable changes of atmospheric pressure without having to swallow or inflate the ears, as the walls of the Eustachian tubes being kept apart, equalisation of pressure takes place during the whole time of the effort.

If, for any reason, a pilot finds difficulty in equalising pressure in his ears, or can equalise the pressure easily in one ear only, and therefore experiences pain or discomfort during flying, medical advice should be sought. Normally both ears should "click" to self-inflation.

From the above, the importance of keeping the mouth and throat in a healthy condition will be appreciated, and care should be taken to avoid excessive smoking, which among other things leads to throat congestion. Care of the teeth is also important, since defective teeth are liable to produce an unsatisfactory condition of the nose and throat.

4. *Clothing.*—Although a specially designed flying suit is issued for the protection of the pilot, other measures are frequently necessary for a pilot's comfort according to the nature of the flight to be undertaken. The main points to be considered are :—

(*a*) the height expected to be reached;
(*b*) the prevailing meteorological conditions;
(*c*) the speed of and protection afforded by the machine.

The main consideration is to prevent the pilot getting cold, since this greatly increases the demand of the body for oxygen in an atmosphere where less is available. During an ascent the drop in temperature is frequently 5° F. per 1,000 feet, so that at altitudes of 30,000—40,000 feet, temperatures of $-50°$ F. to $-70°$ F. may be encountered according to the season of the year and the prevailing meteorological conditions. Efficient body protection is very necessary, therefore, to prevent what is known as a "chill."

The cardinal principle of clothing is to surround the body with a layer of warm air and prevent this. as far as possible, from being dislodged. Such storage of heat is best ensured by surrounding the body with several layers of relatively loosely fitting clothing of different textures, the best materials being wool or silk.

It is the mesh of clothing, not its thickness, which prevents loss of heat. Therefore, two thin woollen vests are of greater service than a single thick one. According to the height of the flight, therefore, a pilot will be well advised to grade the number of garments of relatively thin, closely woven under-clothing, which will provide warmth without unduly hampering movement. For instance, one noted altitude flier found that several thin combination suits worn beneath his flying suit greatly helped in securing warmth at nearly 40,000 feet, where the temperature was approximately 60° below zero.

It is important to remember that under-clothing should not fit too tightly, otherwise, in addition to the fact that insufficient air is stored next the body and the meshes are pressed too closely together, inconvenience may arise from hampering the circulation by pressure on the cutaneous vessels.

As regards flying suits, it is important for protection against cold, that care be taken to close all orifices through which draughts can blow, so preventing dislodgement of the warm air surrounding the body. This is important even when electrically heated clothing is provided.

5. *Protection of the Head and Face.*—It is important that flying caps fit snugly and that the crown of the head be protected by a lining of fur. In the past it was found that the fur lining was not carried over the top of the head, and after flying at 15,000—20,000 feet headaches were aggravated by this cause. In particular, the cap should fit comfortably but tightly in front of the ears, not only to prevent draughts, but also to diminish any deafness which may tend to arise from the noise of the engine or engines.

For high flights it is advisable that a woollen balaclava be worn beneath the cap, so knitted as to come well forward and protect forehead, cheeks and chin. The oxygen mask, which will generally be worn on such flights, serves further to protect the nose and cheeks.

In addition, the face should be smeared with a protective grease to prevent frost-bite. The best grease has been found to be a special petroleum jelly which can now be obtained as an issue. The advice of wearing a balaclava is also good when face grease is used, as this can easily be washed and prevents soiling the edges of the flying cap. For high flights it is advisable also that the flying cap should be fitted with a chin-muff.

Attention has already been drawn to the importance of protection of the eyes.

6. *Protection of the Hands.*—It is important that the hands be adequately protected, since the manual operations of working the throttle, gun, camera, bomb gear, wireless and other apparatus present greatly increased difficulty when the hands are "frozen." Very thick gloves are clumsy. The best ordinary means of protecting the hands is to smear them with grease and then to wear a pair of silk gloves, covered by a pair of woollen gloves beneath the gauntlets. Over the fingers of the gauntlet a finger-muff, attached to the back of the glove, may be worn, which can be slipped off when delicate work has to be done. If necessary, the tips of the first or second finger of the under gloves may be removed so as to enable delicate work, *e.g.*, Morse signalling, to be more satisfactory performed.

When electrically heating devices are provided fur-lined outer gloves are not necessary.

7. *Protection of the Legs and Feet.*—For the upper part of the legs several layers of relatively loosely fitting silk or woollen garments are best.

For the feet two or three pairs of thin closely woven socks are preferable to one thick pair. It is to be remembered that woollen stockings often shrink and tend to fit too tightly. Warmth is also given best by frequent changes of socks (partially woollen) since, when compressed by wear, the heat retaining power is considerably diminished.

Fur-lined boots fitting well up the calf or even to about the knee, or electrically heated soles complete the efficient protection when especially high flights are to be undertaken.

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